CONSTRUCTABILITY IMPLEMENTATION FOR COMPLEX PROJECTS IN SAUDI CONSTRUCTION INDUSTRY

BY

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DEDECATION

I would like to dedicate this work to

My parents who provide me with the required wisdom, patience, passion and who instilled in me the values of life and saw me grow to this stage and made me what I am.

My beloved wife who have always believed in me and encouraged me to follow my dreams.

The Bright Future

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"In the name of Allah, The Most Gracious and The Most Merciful"

اللهُمَّ لكَ الحمدُ حتى ترضى

ولكَ الحمدُ إذا رَضيتْ

ولكَ الحمدُ بعدَ الرضا

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ABSTRACT

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Major Field : CONSTRUCTION ENGINEERING AND MANAGEMENT

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The Saudi construction industry considered one of the largest construction industries in the region. Currently, most of the projects are for re-building the Kingdome infrastructure which considered as complex projects. Hence, the constructability practices implementation become more important to prevent and/or mitigate the project risks that may affect the project success. Many studies and research have been done in the constructability field, yet still there is lack of researches and studies that links the project complexity level with the constructability practices. The main aim of this study is to investigate the impact of implementing constructability practices among the owner, designer/consultant and constructor firms who are executing complex industrial construction projects in the Eastern Province of the Kingdom of Saudi Arabia. To achieve this objective, a questionnaire containing close-ended questions with allowing the participants for more elaboration and/or specifying other answers was developed and distributed among the owner, designer/consultant and constructor firms. In addition, a complex industrial project among the Saudi construction industry that has implanted constructability concept was selected and analyzed as a case study. The level of constructability implementation, constructability implementation techniques, benefits, barriers & success factors and project complexity factors were covered. Moreover, major and minor findings obtained from the conducted case study and/ or the distributed questionnaire were presented and discussed along with the study recommendations.

ملخص الرسالة

الاسم الكامل : صالح علي صالح المفضي

عنوان الرسالة : استخدام "منهج البناء المخطط" للمشاريع المعقدة ضمن صناعة البناء في المملكة العربية السعودية

التخصص : هندسة و إدارة التشييد

تاريخ الدرجة العلمية: مارس ٢٠١٩

تعتبر صناعة البناء السعودية واحدة من أكبر صناعات البناء في المنطقة. حاليا، معظم هذه المشاريع المعقدة هي لإعادة بناء البنية التحتية للمملكة العربية السعودية. وبالتالي، أصبحت ممارسات "منهج البناء المخطط Constructability" أكثر أهمية لمنع و/أو تخفيف مخاطر المشروع التي قد تؤثر على نجاحه. تم إجراء العديد من الدراسات والأبحاث في "منهج البناء المخطط"، ولكن لا يزال هناك نقص في البحوث والدراسات التي تربط مستوى تعقيد المشروع بممارسات "منهج البناء المخطط". الهدف الرئيسي من هذه الدراسة هو دراسة تأثير تطبيق ممارسات "منهج البناء المخطط" على الملاك والمصممين/الاستشاريين والمقاولين الذين يقومون بتنفيذ مشاريع الإنشاءات الصناعية المعقدة في المنطقة الشرقية بالمملكة العربية السعودية. لتحقيق هدف هذه الرسالة، تم تطوير استبيان وتوزيعه على شركات الملاك والمصممين/الاستشاريين والمقاولين. يحتوي هذا الاستبيان على أسئلة تسمح للمشاركين بإضافة المزيد من التفصيل و/أو تحديد إجابات أخرى. بالإضافة إلى ذلك، تم اختيار وتحليل مشروع صناعي معقد من بين المشاريع الصناعية المقامة في المملكة العربية السعودية والتي تم فيه استخدام "منهج البناء المخطط". ضمن هذه الدراسة، تمت تغطية مستوى استخدام "منهج البناء المخطط"، سبل تنفيذه، فوائده، حواجز وعوامل نجاحه. بالإضافة إلى العوامل المؤثرة على مستوى التعقيد في المشروع. قامت الدراسة بمناقشة وبإظهار النتائج الرئيسية والثانوية والتي تم الحصول عليها من خلال دراسة الحالة التي أجريت و/أو الاستبيان الموزع. بالإضافة إلى تقديم التوصيات والتي بدورها تسهم في تطوير ممارسات "منهج البناء المخطط" من قبل الملاك والمصممين/الاستشاريين والمقاولين الذين يقومون بتنفيذ مشاريع الإنشاءات الصناعية المعقدة في المنطقة الشرقية بالمملكة العربية السعودية.

CHAPTER 1: INTRODUCTION

1.1 General

The construction industry for most of the developed and developing countries play a significant impact on its Gross Domestic Product (GDP) (Kifokeris and Xenidis, 2017). The Saudi construction industry considered one of the largest construction industries in the region (El-Malki, 2013). The rapidly growth in the Saudi construction industry is due to two main factors. First, the government strategy to re-build the Kingdom’s infrastructure. Second, the significant demand on the private sector (Al-Otaibi and Price, 2010). According to Ventures Middle East LLC (2011), $575 B is the amount that was spent between 2008 and 2013 in Saudi construction industry for the public construction projects (Al-Gahtany et al., 2016). $610 B is predicted to be spent in the Saudi construction industry between 2015 and 2020 (Al-Rashed et al., 2014).

Currently, most of these projects are for re-building the Kingdome infrastructure which considered as complex projects due to many factors (the large-scale, huge involvement of international and national organizations, the location of these projects … etc.). Hence, due to the complexity nature of re-building the Kingdome infrastructure, the constructability practices implementation become more important to prevent and/or mitigate the project risks that may affect the project success.

Constructability practices can be one of the construction management tools that can be utilized to resolve and minimize the construction project complexity (Kifokeris and Xenidis, 2017). The most critical criterion for project frailer is the poor practices for risk management and there is a clear lack of implementing these practices in the Saudi construction industry (Al-Bogamy and Dawood, 2015).

1.2 Statement of The Problem

The constructability practices implementation become more important to prevent and/or mitigate any potential risks that may affect the project success due to the rapidly growth of the project complexity in the construction industry (Kifokeris and Xenidis, 2017). The Project Management Institute (Project Management Institute, 2013) in their published in-depth report “Navigating Complexity” they have stated that the” Complexity is not going away and will only increase”. According to Baccarini (1996), the importance of identifying and understanding the complexity of any project to the project management process is that to help them in determining the required planning, coordination and level of control.

Many studies and researches have been done to improve the constructability practices, yet still there is lack of researches and studies that links the effect of the project complexity level on the constructability practices for industrial construction projects. The research and practice of constructability implementation for the local complex industrial construction projects has not been given a sufficient attention which has promoted this research study. This study will provide the required answers for the following questions that have been raised during the literature review:

- What is the current level of constructability implementation for complex industrial projects in the Saudi construction industry?
- How constructability been implemented for complex industrial projects in the Saudi construction industry?
- How can constructability impact the performance of complex industrial projects in the Saudi construction industry?
- What are the success factors and barriers for implementing constructability in complex industrial projects in the Saudi construction industry?

1.3 Objective of The Study

The main aim and objective of this study is to investigate the impact of implementing constructability practices on the private and semi-government complex industrial projects in the Saudi construction industry. To achieve the main aim and objective of the study, the following items will be covered in this study:

- Measuring the level of constructability implementation among the private and semi-government owners;

- Identifying the complexity criteria that the private and semi-government owners use to measure the level of complexity for their projects;

- Identifying the techniques used for implementing constructability among the private and semi-government owners;

- Identifying the constructability implementation barriers for complex industrial projects among the private and semi-government owners;

- Identifying the constructability implementation benefits for complex industrial projects among the private and semi-government owners; and

- Identifying the success factors for implementing constructability for complex industrial projects among the private and semi-government owners.

1.4 Significant of The Study

Many studies have been conducted to improve the implementation of constructability practices, yet still there is limited researches that links the effect of the project complexity level on the implementation of constructability practices. This study would be a significant attempt toward promoting the local industrial projects in the Saudi construction industry by measuring the level of constructability implementation and investigate its impact on the complex industrial construction projects among the private and semi-government owners. In addition, exploring the major success factors, barriers, benefits and techniques for implementing constructability practices on the complex industrial construction projects among private and semi-government owners. Moreover, this study will provide areas of improvement for the constructability concept implementation in the Saudi construction industry, in particular related to complex projects. Furthermore, this study will suggest further areas of research that emphasize constructability implementation among the complex industrial projects in Saudi construction industry.

On the other hand, private and semi-government owners will highly benefit from this study in addition to the design offices, engineering and consulting firms, constructors, project management team. Moreover, this study will highly benefit the interested researchers from the academia by expanding the existing literature and serve as a future reference to improve the constructability practices implementation.

1.5 Scope and Limitation

This study will be limited to the complex industrial construction projects carried by the private and semi-government owners in the Saudi construction industry. In addition, this study will be also limited to the major engineering, consultants and construction firms who are executing complex industrial construction projects in the

Saudi construction industry. Due to the time and cost constraints, this study will be also limited to these projects located and executed in the Eastern Province of the Kingdom of Saudi Arabia.

CHAPTER 2: LITERATURE REVIEW

2.1 Constructability

2.1.1 Introduction

According to Kifokeris and Xenidis, (2017), In 1960s many researchers in the United Kingdom such as; Emmerson (1962) and Banwell (1964) have concluded that the lack of communication between the construction team and the design team is one of the root causes for many failures in the construction industry for satisfying the project objectives. After these studies, the buildability concept was introduced to the construction industry and defined by the Construction Industry Research and Information Association (Construction Industry Research and Information Association, 1983) as "The extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building". However, the buildability concept covers only the design issues that can affect the project completion in a successful manner, and this will make this concept incomprehensive to address all the project risks (Wong et al., 2007).

The buildability concept opens the window for many researchers to think about a concept that having a broader scope that would combine all the project lifecycle to achieve the project objectives; time, budget, quality and overall owner satisfaction (Kifokeris and Xenidis, 2017).

2.1.2 Constructability definitions

In 1986, the Construction Industry Institute (CII) for the first time has defined the constructability as " The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives". This definition of constructability which introduced by the CII considered as the most comprehensive definition of constructability, up today, despite all the effort done by many researchers to define the constructability (Kifokeris and Xenidis, 2017).

In 1991, the Construction Management Committee of the ASCE has defined the constructability program as “The application of a disciplined, systematic optimization of construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel who are part of a project team”. The constructability program can be a useful approach to identify and tackle all the causes of not satisfying the project's objectives at its early stage of the project's lifecycle (Gambatese et al., 2007).

In 1992, CII Australia has involved in improving the constructability concept by introducing the constructability principle file. Later in 1996, CII Australia also contributed to improve the constructability concept by developing a constructability implementation guideline (Wong et al., 2007).

2.1.3 Constructability concepts and tools

Constructability concepts are implemented throughout the project's lifecycle. First, in the project initiation phase where the feasibility study and the conceptual planning are performed in addition to the contractual procurement of the design and construction. Second, in the project execution phase where the detail design is conducted and the actual implementation of the project in the field. Finally, in the project delivery phase where the project is delivered to its owner (Nawi et al., 2009).

The CII has developed total of seventeen (17) constructability concepts to enhance the constructability of a project. These constructability concepts were developed to be practiced in the project's major phases. Eight (8) of these constructability concepts are applicable to the conceptual planning phase as following:

1) **Constructability program is an integral part of project execution plan:** At the early phase of any project, where the project execution plant is developed, a clear written plan on how to implement the constructability should be provided to achieve the constructability program objectives.

2) **Project planning involves construction knowledge and experience:** The effective interconnection between the design and the construction should be achieved throughout the involvement of expertise and practitioners. Sharing the expertise and practitioner's knowledge and experience during the conceptual planning would lead to more chance in achieving the project's objectives.

3) **Early construction involvement is considered in development of contracting strategy:**

Regardless of the selected project delivery system for a project, the contract framework that governs the project should highlight the required construction personnel qualifications.

4) **Project schedules are construction-sensitive:**

At the earliest possible, the project schedules goals should be developed as construction driven.

5) **Basic design approaches consider major construction methods:**

To smoothly implement the project's design during the field operations stage, the primary construction methods should be determined in the design stage.

6) **Site layouts promote efficient construction:**

The site's layout (site access, fabrication yard, storage area and truck roads ... etc.) of a project should be carefully studied to ensure safe and productive work environment.

7) **Project team participants responsible for constructability are identified early:**

The constructability program team should be carefully selected based on their knowledge and experience. Also, all the project's stakeholders should be involved in this team to ensure that the constructability recommendations will be tracked till the implementation.

8) **<u>Advanced information technologies are applied throughout project:</u>**

Taking the full advantages of the current developed construction technologies such as; Building Information Modeling (BIM), simulation, risk analysis software and 3D modeling.

Eight (8) constructability concepts are applicable to the design and procurement phases as following:

9) **<u>Design and procurement schedules are construction sensitive:</u>**

Planning the sequence of the construction activities should be conducted during the design and the resources procurement stages.

10) **<u>Designs are configured to enable efficient construction:</u>**

The designer should keep in mind that his design needs to be as simple and rational as possible for the construction personnel to enable them to efficiently implement the design.

11) **<u>Design elements are standardized:</u>**

The standardization concept for project's elements size, material types and specifications ...etc. would be preferred to be considered during the design stage to reduce the construction complexity, time and cost of a project without sacrificing the project's final output quality.

12) <u>Construction efficiency is considered in specification development:</u>

The technical specifications for materials and equipment should be simplified for effective construction without sacrificing the project’s final output quality.

13) <u>Module/preassembly designs are prepared to facilitate fabrication, transport, and installation:</u>

The designer should also keep in mind the modularization and preassemble concepts for systems and/or equipment during the development of the project’s design. Such concepts need to be carefully studied from applicability (i.e. availability, transportation, installation, operability, maintainability…. etc.) and economically point of view.

14) <u>Designs promote construction accessibility of personnel, material, and equipment:</u>

The designer should also keep in mind the resources (manpower, materials, equipment) allocation and its accessibility to the project’s site. Indecorous allocation of the project’s resources would impact the project’s productivity and safety in a negative way. Hence, the project will fail to achieve its fundamental goals (time, cost, quality and the project's owner satisfaction).

15) <u>Designs facilitate construction under adverse weather conditions:</u>

The adverse weather conditions should be taken into consideration during the design stage. Modularization, preassembly and prefabrication can be considered as preventive methods for any unforeseen bad wither conditions.

16) **<u>Design and construction sequencing should facilitate system turnover and start-up:</u>**

During the design stage, the designer should also plan for the project’s start-up phase. The project’s start-up plan should be developed and clearly written. The start-up plan should be carefully reviewed by expertise at the early stage of the project to avoid any potential delay.

Finally, one concept is applicable to the construction operations phase which is the construction innovation utilization to enhance the constructability of a project.

The implementation of the above-mentioned constructability concepts, with proper adjustment for each project, will prevent many problems accrue in the construction projects. Hence, the project’s team will be able to achieve the fundamental objectives of the project such as; Time, Cost, Quality and the overall owner's satisfaction (Kifokeris and Xenidis, 2017).

Various tools and approaches have been introduced and developed by precisions and professionals in the construction industry that aims to achieve the fundamental objectives of any project (Time, Cost, Quality and the overall owner's satisfaction). These tools and approaches such as; Planning & Operations Performance Evaluation, Value Engineering, Knowledge Management, Cost/Benefit Analysis, Total Quality Management, Hybrid Value Engineering, Object-Oriented Analysis and The Total Buildability Performance Framework. In fact, the previously mentioned tools and approaches provides input to the constructability practices (Kifokeris and Xenidis, 2017).

During the past years, various tools have been developed to facilitate the constructability implementation and to support the development of construction projects throughout its lifecycle (the initiation, execution and delivery phases). In addition, these tools can be utilized for the evaluation and assessment activities of the project delivery. On the other hand, these tools could also be utilized for improving the assessment and evaluation outcomes or prototype studies (Kifokeris and Xenidis, 2017).

Kifokeris and Xenidis (2017) did an extensive literature review on the tools that implant constructability concepts. These constructability tools have been categorized and distinguished in two different ways: Type-wise (Cognitive, Mathematical, Methodological, Programming, And Software) and Nature-wise (Quantitative Project Features' & Indices' Assessment Tools, Qualitative Project Features' & Indices' Assessment Tools, Schedule-Cost Quality Management & Decision-Making Tools, Program Review Tools, Information & Knowledge Feedback Tools, and Acquired Knowledge Recording, Management & Dissemination Tools). 37 tools for implementing constructability have been reviewed and findings are the following:

- None of the qualitative and quantitative project featured' and indices' assessment tools are applied in the initiation and delivery phases of a construction project. However, the constructability tools are equally applied (regardless of their nature) throughout the construction project phases;

- The nature of the project is not a factor to be considered when selecting the most suitable constructability tool to be implemented by the project's team;

- More than 97% of these constructability tools have the methodological concept as part of the tool;

- Less than 50% of these constructability tools depends on a computer software; and

- Most of these tools, regardless of their type and nature, are applied by the project team in the execution phase of the construction project.

In the early 1990s, the CII in the United States of America and the CII of Australia has collaboratively developed the Constructability Principles File that tailored to the Australia construction industry (Construction Industry Institute of Australia, 1993). The Constructability Principles File highlights twelve (12) principles which considered as the general fundamentals for implementing the constructability concepts and the constructability program. The constructability principles are elaborated as follow (Adams, 1989; Construction Industry Institute of Australia, 1993; Griffith and Sidwell, 1997):

1. **Project Integration:** The constructability must be part of the developed project plan.

2. **Construction knowledge:** The construction expertise must be involved in the project planning phase.

3. **Team skills:** The project team must be selected based on their experience, knowledge and skills requirement for the project.

4. **Corporate objectives:** The project team need to understand the project objectives as well as the client's objectives so that the constructability can be enhanced.

5. **Available resources:** In the project's design phase, the available resources (manpower skills, equipment and technologies) must be considered.

6. **External factors:** External factors such as; unforeseen bad weather, political issues ...etc. could affect the project cost and/or schedule.

7. **Program:** The project program must be construction-sensitive, realistic and have the commitment of the project team.

8. **Construction methodology:** In the project's design phase, the construction methodology must be considered.

9. **<u>Accessibility</u>:** In the project's design and construction phase, the construction accessibility needs to be considered to enhance the project's constructability.

10. **<u>Specifications</u>:** The projects constructability can be enhanced by developing transparent specifications.

11. **<u>Construction innovation</u>:** The projects constructability can be enhanced using innovation ideas during the construction stage.

12. **<u>Feedback</u>:** The projects constructability can be enhanced by utilizing the lesson-learned databases and best-practices for other projects.

The constructability team may find that some of these constructability principles are not applicable for their project, but the main objective if these constructability principles is to facilitate the constructability implementation throughout the project's lifecycle (Griffith and Sidwell, 1997).

2.1.4 The importance of constructability practices

Four critical criteria have been identified as the main factors affecting the success of any project. The main four objectives of any project are the following; 1) Project time completion, 2) the project completed within the allocated budget, 3) the overall project quality and 4) the overall satisfaction of the project's owner (Poon et al., 1999). Due to the rapidly growth of the project complexity in the construction industry, the constructability practices implementation become more important to prevent and/or mitigate any potential risks that may affect the project success (Kifokeris and Xenidis, 2017). Kifokeris and Xenidis (2017) also highlighted that the interconnection and communication among any project's stakeholders throughout implementing the constructability concepts is crucial and important to achieve the project objectives. It is worth mentioning that the constructability practices are suitable for all types of technical projects and applicable to all stages of the project's life-cycle (Kifokeris and Xenidis, 2017).

2.1.5 Constructability implementation

According to Griffith and Sidwell (1995), Constructability System Process is the start for implementing the constructability. Figure 1 illustrates the constructability system process:

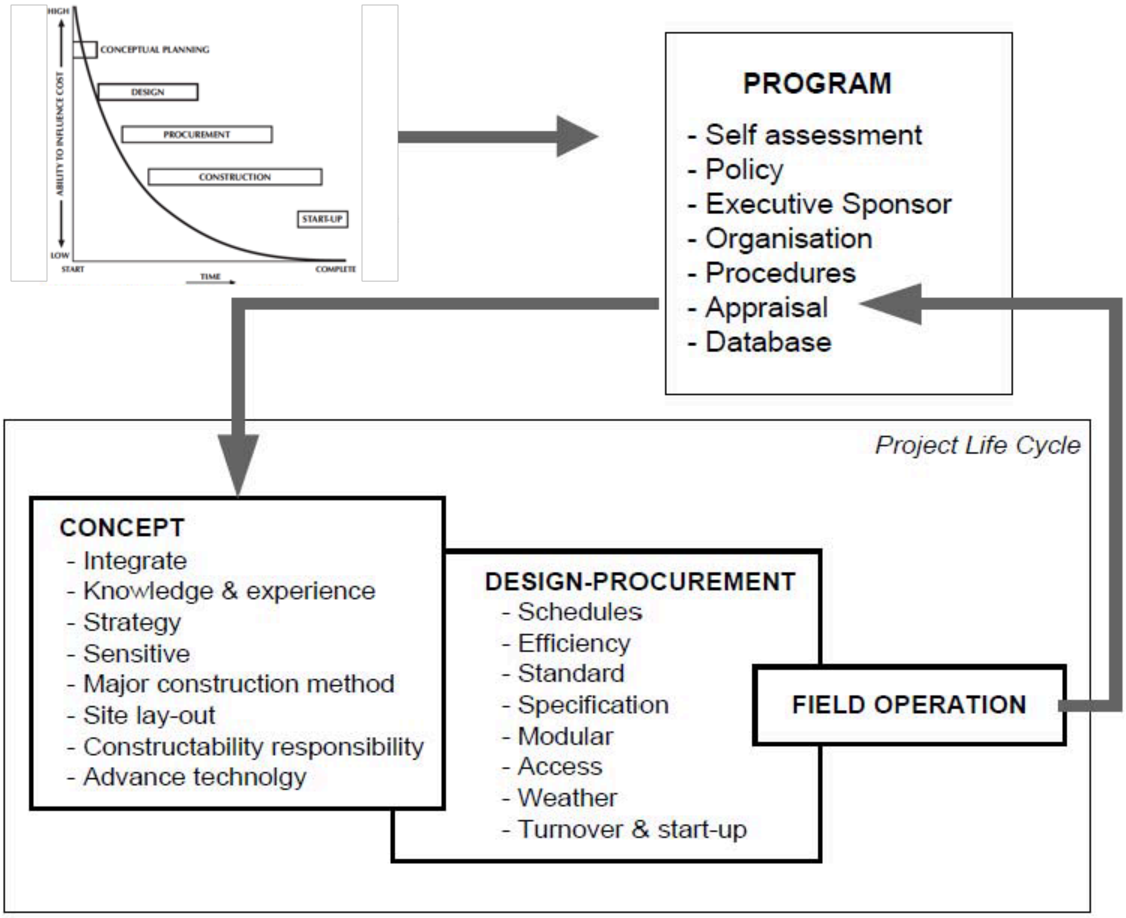

Figure 1: Constructability System Process (Griffith and Sidwell, 1995)

However, different organization will have different constructability system to be adopted. To have a successful constructability program that’s fit every organization, eleven (11) elements are required to be present as following (Trigunarsyah, 2001):

- Recognizing that early decision-making could influence the project cost;
- Top management commitment and support of constructability;
- Single point champion of the constructability;

- Continues corporate constructability program with implementing customized constructability program for each project;

- Utilizing the constructability program by the clients to achieve the project's objectives;

- Designers willingness to receive and review the construction input;

- Experienced construction personnel involvement at the early stages of the project;

- Utilizing familiar procedures and methodologies;

- Company Lesson-Learned Database;

- Training when required; and

- Simple feedback and evaluation.

A team from the University of Wisconsin was commissioned by the CII to study the implementation of the constructability programs. From their literature review, three types of constructability programs were identified as following (Russell, Gugel & Radtke, 1992):

- Corporate-Level Constructability Programs;

- Project-Level Constructability Programs; and
- Constructability Review Programs.

2.1.5.1 corporate-level constructability programs

The CII (Construction Industry Institute, 1987) concluded that an affective and successful implementation of the constructability requires a permanent constructability program at the corporate level. Hence, the project will have the needed support from the organization’s executives and top managements. On the other hand, implementing the constructability program at the corporate level will assure that the project’s objectives will be aligned with the overall corporate strategies and objectives. To develop a corporate-level constructability program, several important actions that need to be considered as recommended by the CII. Figure 2 shows these recommended actions:

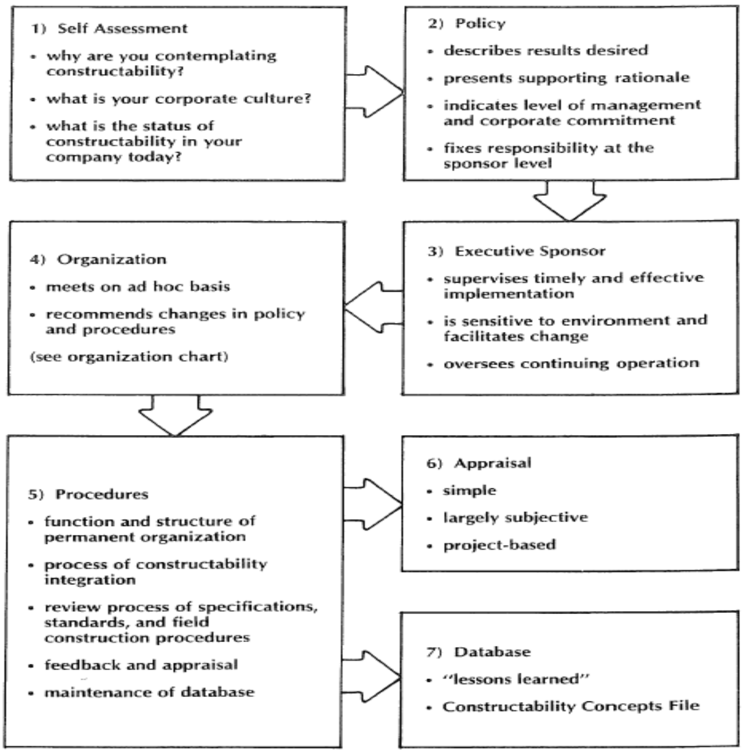

Figure 2: The Company Constructability Program (Construction Industry Institute, 1987)

2.1.5.2 project-level constructability programs

To gain the desirable benefits of implementing the constructability, it needs to be established and lunched at the very early stages of the project's life-cycle (Construction Industry Institute, 1986). Several factors that can influence the selection of the most suitable constructability program at the project level such as; Contractor qualification, Project logistics, Project team level of experience and Cost & Schedule constrains (Trigunarsyah, 2001). However, several important characteristics for a successful constructability program at the project level were suggested by the CII (Construction Industry Institute, 1987) and the CIIA (Francis and Sidwell, 1996) as following:

- Project’s owner support to the constructability program;

- Project’s team commitment to the constructability program;

- Constructability system, objectives and principals training for the project’s team;

- Early input and involvement from the construction team;

- Written procedures that fits the project’s uniqueness; and

- Simple and largely subjective evaluation.

Figure 3 shows the actions that need to be performed to implement the constructability program at the project level (O’Connor, 2006):

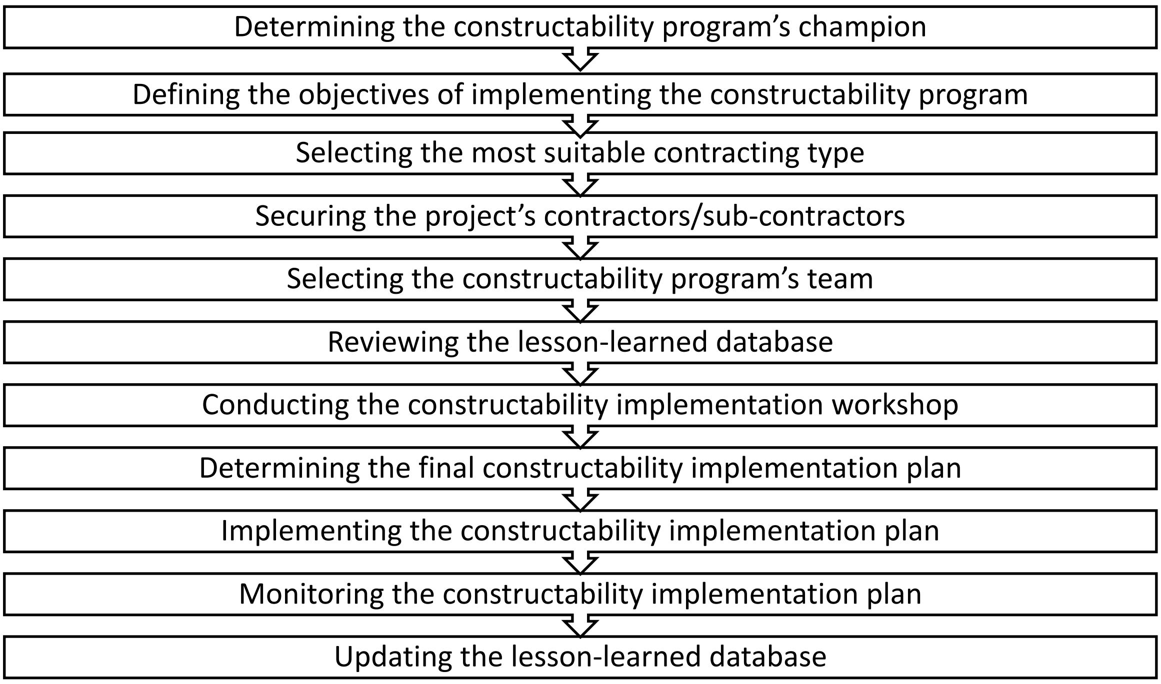

Figure 3: Project Level Constructability Program Implementation Actions (O’Connor, 2006)

Many approaches were suggested for the constructability programs implementation at the project level. Moreover, these approaches are organization's and project type's dependent. However, these approaches are not meant to measure the constructability program's effectiveness. They meant to be used as an indication of the organization support given to the constructability program (Russell, Gugel & Radtke, 1992). They also classified these approached into four general groups as following:

- Formal project-level constructability program;
- Formal post-facto constructability review;
- Informal application of constructability; and
- Untimely constructability input.

Figure 4 summarize the set of sequential process for implementing the corporate level and the formal project level constructability programs:

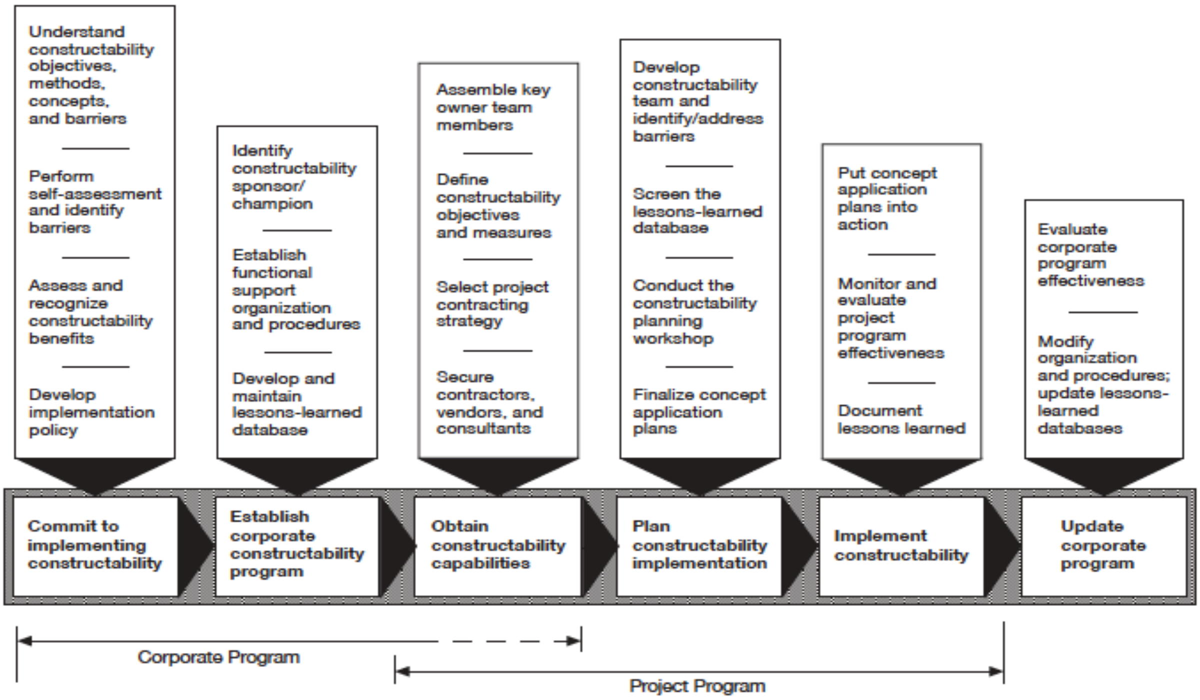

Figure 4: Constructability Implementation Roadmap (Russell et al., 1992)

2.1.5.3 constructability review program

According to Trigunarsyah (2001), these types of constructability programs are scheduled to be conducted at different intervals in the design phase of the project life-cycle. In addition, these constructability review programs are more of utilizing some design checklists review. So, this approach can be described as a reactive approach instead of a pro-active approach.

2.1.6 Constructability implementation & Contracting strategy relationship

Constructability as a holistic managerial approach applied in all over the project's lifecycle (initiation, execution and delivery phases) could be greatly affected by the contractual procurement type and/or the delivery method of the project. The design-Build project delivery system is strongly enhancing the implementation of the constructability and satisfying its concepts (Mahdi and Alreshaid, 2005). This is because of that the contractor who will design the project will be also responsible for implementing the design in the field (Ogunsanmi et al. 2011). On the other hand, absence of studies that evaluate the constructability implementation in other project delivery system such as; traditional design-bid-build, Construction management at risk, build-operate-transfer ... etc. (Kifokeris and Xenidis, 2017)

2.1.7 Constructability implementation in The Saudi Construction Industry

(Assaf, Jannadi and Al-Yousif, 2003) conducted a study to examine whether or not the general contractors in the Eastern Province of Saudi Arabia are performing the constructability concept in their projects. In this study, more than 30 general contractors were examined. They have concluded that the general contractors in the Eastern Province of Saudi Arabia are familiar with the constructability terms and have a good level of constructability awareness. 71% of these general contractors believes that the constructability should be implemented in all projects, 26% believes that it should be implemented in large projects and 16% believes that it should be implemented in complex projects. On the other hand, as a result of their study, 77% of the general contractors are implementing the constructability practices during the pre-construction phase of the project life-cycle.

2.1.8 Constructability implementation barriers

2.1.8.1 general barriers

Constructability practices are very helpful and useful to the project's team that will lead them to achieve the fundamental objectives of the project (Time, Cost, Quality and the overall owner's satisfaction). During the past years, many studies have been conducted to determine the constructability implementation barriers. Total of 41 barriers to the constructability implementation was examined on 62 companies to identify the barriers encountered the most frequently within these companies. Out of these 41 constructability barriers, total of 18 barriers was identified as the most common barriers for implementing the constructability in any project (O'Connor and Miller, 1994). These 18 common barriers for implementing the constructability are as following:

1. Complacency with the status quo;
2. Unwillingness to spend additional money and/or effort at the early stages of the project's life-cycle;

3. Limitations of lump-sum competitive contracting;

4. Designer’s lack of experience in construction;

5. Designer's perception that they are doing it;

6. Lack of collaboration between designers and constructors;

7. Construction input is requested too late;

8. Believing that there are no proven benefits when implementing constructability;

9. Owner's lack of understanding the constructability concepts;

10. Misdirected measurement of the designer’s performance and the design objectives;

11. Owner's perception that they are doing it;

12. Lack of real commitment to constructability;

13. Designer's lack of understanding the constructability concepts;

14. Constructor’s lack of communication skills;

15. Lack of documentation and lessons-learned database;

16. Lack of team-building or partnering;

17. Construction input is received late; and

18. The right individuals for constructability are not available.

In addition, extensive efforts have been conducted to consolidate and identify the constructability implementation barriers (Jergeas and Put, 2001; Ahmad and Othman, 2011).

2.1.8.2 constructability barriers in the Saudi construction industry

It is worth highlighting that even with the good level of constructability awareness among the general contractors in the Eastern Province of Saudi Arabia, still more effort need to be performed to eliminate the existing barriers for implementing constructability. These constructability barriers were highlighted by the general contractors as following (Assaf, Jannadi and Al-Yousif, 2003):

- In the traditional form of contracting, the design is completed without the construction inputs;

- No attention from the project’s owner regarding to constructability in the contracting strategy;

- The projects owners do not ask for implementing constructability in their projects;

- Some owners do not know what the constructability concept is;

- Unwillingness of field personnel to share their pre-construction advise;

- Some contractors do not know what the constructability concept is;

- Some designers do not know what the constructability concept is; and

- Designer’s lack of experience in construction and construction technologies.

2.2 Project Complexity

2.2.1 Introduction

The construction industry has become more complex since World War II (Baccarini, 1996). The Project Management Institute (PMI) in their published in-depth report “Navigating Complexity” they have stated that the” Complexity is not going away and will only increase” (Project Management Institute, 2013). The construction industry understand that the project complexity will affect any project in many aspects such as; the project management practices requirement and the overall project performance and delivery (Kermanshachi et al., 2016). Complexity can be considered as one of the most debatable and important topics in the project management field (Bakhshi et al., 2016). Even with the existing extensive researches and studies on the project complexity topics, still there is a lack of accepted conceptual definition for complexity among researchers (Bakhshi et al., 2016; Ireland, 2013).

Bakhshi et al., (2016) have conducted a comprehensive and systematic literature review to define complexity from project management point of view. The conducted analysis involved reviewing more than 400 publications starting from early 90's to 2015. This study has highlighted the major historical milestones of project complexity. Figure 5 shows the major historical milestones of project complexity.

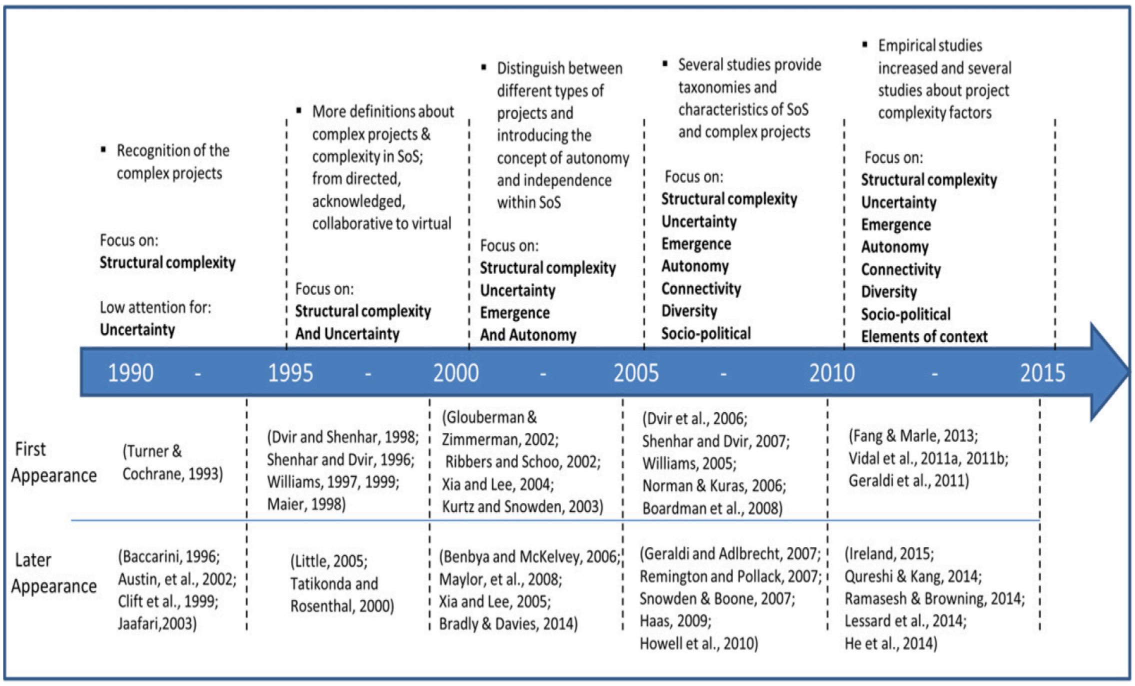

Figure 5: Milestones of Project Complexity History (Bakhshi et al., 2016)

2.2.2 Complex project definitions and concepts

It has been found that complexity, in concept, can be understood in various ways in different fields and sometimes even within the same field (Mozaffari et al., 2012). In fact, there is no standard definition for the project complexity that is applicable to all the construction project cases (Bakshi et al., 2016). Hence, there is a need to define the project complexity and study it's attributes and what can influence the complexity of any project (Kermanshachi et al., 2016).

Many studies and research have been done to define and identify the meaning of project complexity due to the rapidly growth of the project complexity all over the world (Vidal et al., 2011). Baccarini (1996) define the project complexity as "Consisting of many varied interrelated parts" and this definition is applicable to all project dimension related to the project management process (organization, technology, environment, information, decision making and systems). Project complexity can be defined as” The measure of the difficulty of implementing a planned production work flow in relation to any one or number of quantifiable managerial objectives” (Gidado,1996). Vidal et al., (2011) and other researchers do agree to define the project complexity as “project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behavior, even when given reasonably complete information about the project system”. Kermanshachi et al., (2016) used the following definition as the basis for their research about the project complexity indicators "Project complexity is the degree of interrelatedness between project attributes and interfaces, and their consequential impact on predictability and functionality". Bakshi et al., (2016) developed a definition for project complexity as " An intricate arrangement of the varied interrelated parts in which the elements can change and evolve constantly with an effect on the project objectives".

2.2.3 Managing complex projects

Complexity system can be defined as " A complex system is a system (whole) comprised of numerous interacting entities (parts), each of which is behaving in its local context according to some rules, laws and forces. In responding to their own particular local context, these individual parts, can, despite acting in parallel without explicit inter-part coordination or communication, cause the system as a whole to display emergent patterns – orderly phenomena and properties– at the global or collective level" (Maguire and McKelvey, 1999). A construction project can be considered as a complex system due to several factors that are difficult to be controlled by the project management (Whitty and Maylor, 2009).

Managing projects to achieve its fundamental goals requires to identify certain critical characteristics and some researches in the construction industry pointed out that the project complexity is one of those critical characteristics (Kermanshachi et al., 2016). Even if the project team have all the needed information about the project, project complexity will still exist which make it difficult to keep every part of the project under control (Vidal et al., 2011). Measuring the project complexity is a challenging activity for the project teams to achieving the project objectives (Kermanshachi et al., 2016).

According to Baccarini (1996), the importance of identifying and understanding the complexity of any project to the project management process is that to help them in determining the required planning, coordination and level of control (Baccarini, 1996). Understanding past experience of success and failure while focusing on the project complexity factors will help project managers in managing complex projects (Bakhshi et al.,2016). Moreover, understanding the project complexity, from management point of view, is very essential and significantly important to the project's stakeholders. Identifying the complexity of any project will help the team in many aspects as following (Baccarini, 1996):

- Clearly understand the main goals and objectives of the project;
- Determine the planning, coordination and control requirements;
- Determine the required resources and procurement arrangement; and
- Influencing the project's fundamental goals (Time, Cost and Quality).

In the construction industry, complex projects are requiring special tools and system from management point of view. On the other words, the developed management practices, tools and systems for conventional projects have been found ineffective to be implemented for complex projects (Morris & Hough, 1993).

2.2.4 Attributes of complexity

Over the last two decades, many studies and researches have been conducted to identify the complexity attributes more than any other subject in the project complexity (Construction Industry Institute, 2015). Baccarini (1992) introduced two major attributes of complexity. The fist attribute is the Organizational complexity which reflects the differentiation and connectivity of the project elements and tasks. Three years later, this attribute of complexity was described as the Structural complexity (Williams, 1999). The second attribute is the Technological complexity which reflects the utilization of resources to convert inputs into outputs. This attribute of complexity can be divided into three elements as following (Construction Industry Institute, 2015):

- The facility operation requirements;
- The project characteristics; and
- The level of knowledge requirements.

Lebcir (2006) identified one more factor influencing the project complexity which is the Uncertainty. This factor has two dimensions. The first dimension the uncertainty in the project's goals. The second dimension is the uncertainty methods for achieving the project's goals. According to Shenhar (2001), construction projects have lower level of uncertainty comparing with those projects in the IT or defense industry due to the higher degree of innovation required in these types of projects. Remington and Pollack (2007) introduced two more major attributes of complexity. The first attribute is the Directional complexity which reflects the absence of totally agreed on the project's goals among all the project's stakeholders. The second attribute is the Temporal complexity which reflects the environmental effects on the project duration.

On the other hand, Brockmann and Girmscheid (2007) believes that the Structural complexity, Technological complexity, Directional complexity and Temporal complexity do not cover all the complexity aspects. Hence, they have introduced Four different attributes of complexity. The first attribute is the Social complexity which reflects the communication number and level between the project's manpower. The second attribute is the Cultural complexity which reflects the project stakeholders' history experience and decision-making processes. The third attribute is the Operative complexity which reflects the level of independency of an organization which involved in the project during the decision-making processes. The fourth attribute is the Cognitive complexity which related to the possibility of self-reflection or individual sense making process in the project. Hass (2009) concluded that the Project Details, Ambiguity, Uncertainty, Unpredictability, Dynamics and Social structure are some sources of project complexity.

2.2.5 Project complexity factors

All types of projects have certain level of complexity and the level of complexity varies from project to project depending on many factors (Bakhshi et al., 2016). According to the CII (2015), there is a clear lack of integrated studies that defines the project complexity, identifies its attributes and introduces methods to identify the project complexity degree of each project in the construction industry. the CII highlighted in their study that the construction industry significantly needs for an efficient complexity modeling to identify and manage the project complexity factors for a project. The CII team (RT 305) conducted a comprehensive study to define the project complexity, identify the attributes of complexity, identify most significant project complexity indicators in order to measure the level of complexity of a project and suggest management strategies for each identified project complexity indicator. In this study, more than one hundred project complexity indicators related to 40 attributes of complexity that potentially could affect the project complexity level in the construction industry was identified and categorized into eleven categories (Stakeholder Management, Governance, Fiscal Planning, Quality, Legal, Interfaces, Execution

Target, Design & Technology, Location, Scope Definition and Project Resources). Out of these project complexity indicators, they have identified total of 37 project complexity indicators than can influence project complexity level (i.e. Low complexity project or High complexity project). These 37 key complexity indicators are representing 23 attributes of complexity which belonging to 11 categories of project complexity. However, these 37 complexity indicators may not be applicable to all the projects in the construction industry. Table 1 shows the related category and attribute for all the 37 key complexity indicators (Construction Industry Institute, 2015):

CATEGORY	ATTRIBUTE	COMPLEXITY INDICATOR
Stakeholder Management	-Strategic important of the project	-Influence of this project on the organization's overall success
	-Project impact of local social and political groups (stakeholders)	-Impact of required approvals from external stakeholders on the original project execution plan
		-Impact of required inspection by external (regulatory) agencies/entities on original project execution plan
Governance	-Joint ventures -Owner, partnerships	-Total number of JV partners in this project
	-Level of authorizing approvals and duration of receiving proposals -Level of control	-Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan
		-Number of times on this project that a change order will go above the Project Manager for approval
Fiscal Planning	-Fiscal planning, or financing (funding stream, uncertain political environment)	-Number of funding phases (gates) from concept to project completion
		-Specific delays or difficulties in securing project funding
Quality	-Quality of suppliers, subcontractors, contractors	-Quality of bulk materials during project execution
Legal	-Permitting and regulatory requirements	-Number of total permits to be required
		-Level of difficulty in obtaining permits.
		-Difficulty in obtaining design approvals
	-Legal	-Impact of external agencies on the project execution plan
Interfaces	-Interfaces within the project -Number of participants	-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project
		-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project
		-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the construction phase of the project

Execution Target	-Cost targets	-Compare target project funding against industry/internal benchmarks
	-Schedule targets	-Compare target project schedule against industry/internal benchmarks
Design & Technology	-Design (number of process steps, HSE hazards, # of recycles, exotic materials)	-Difficulty in system design and integration on this project compared to a typical project for your company
	-Technology	-Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase
		-Company's degree of familiarity with technologies that will be involved in construction project phase
		-Company's degree of familiarity with technologies that will be involved in operating facility project phase
Location	-Number of locations	-Number of execution locations which will be used on this project during detailed engineering/design phase
	-Logistics	-Number of execution locations which will be used on this project during fabrication (bulk materials and equipment) phase
		-Impact of project location on the project execution plan
	-Physical location	-Project location is remote from highly populated areas
		-Level of infrastructure existing at the site to support the project
Scope Definition	-Change Management (dynamics of market and environment)	-Identify the percentage of engineering/design completed at the start of construction
		-Clarity of the change management process to key project team members
		-Impact of the magnitude of change orders on project execution
		-Impact of the timing of change orders on project execution
		-RFIs drive project design changes
Project Resources	-Direct field labor management	-Percentage of project/construction management staff who will work on the project compared to planned project/construction management staff
	-Resource availability	-Quality issues of skilled field craft labor during project construction
	-Resource availability	-Frequency of workarounds (work activities out of sequence to continue) because materials are not available when needed to support construction
	-Turn over	-Percentage of craft labor turnover
		-Percentage of craft labor sourced locally (within 100 miles radius of job site).

Table 1: Key Project Complexity Indicators (Construction Industry Institute, 2015)

Out of the above mentioned 37 key complexity indicators, the CII team have identified total of 4 key project complexity indicators than can have impact on the cost performance and the schedule performance of a project. These 4 key complexity indicators are representing 2 attributes of complexity which belonging to 2 categories of project complexity. Table 2 shows the related category and attribute for these 4 key complexity indicators (Construction Industry Institute, 2015):

<table>
<tr><th>Directly Impact</th><th>CATEGORY</th><th>ATTRIBUTE</th><th>COMPLEXITY INDICATOR</th></tr>
<tr><td rowspan="3">Cost Performance</td><td>Stakeholder Management</td><td>-Strategic important of the project</td><td>-Influence of this project on the organization's overall success</td></tr>
<tr><td rowspan="2">Legal</td><td>-Permitting and regulatory requirements</td><td>-Difficulty in obtaining design approvals</td></tr>
<tr><td>-Legal</td><td>-Impact of external agencies on the project execution plan</td></tr>
<tr><td>Schedule Performance</td><td>Quality</td><td>-Quality of suppliers, subcontractors, contractors</td><td>-Quality of bulk materials during project execution</td></tr>
</table>

Table 2: Key Project Complexity Indicators Directly Impact Cost & Schedule Performance (Construction Industry Institute, 2015)

In general, the CII team concluded that these 37 key complexity indicators do not have a direct impact on the project performance. However, the team highlighted that these 37 key complexity indicators may have indirect impact on the project practices and decisions which then lead to impact the project performance success.

Later on, a study on the identified complexity indicators by the CII was conducted by utilizing a qualitative Delphi method. Mix of ten (10) Subject Matter Experts from clients, contractors and consulting companies were part of this study. This study conclude that the following are the top three project complexity indicators (Kermanshachi et al., 2016):

- Peak number of participants on the Project Management Team during engineering/design phase of the project;

- Magnitude of change orders impacting project execution; and

- Frequency of the workarounds.

Bakhshi et al., (2016) concluded that the degree of complexity of any project could affected by many factors. In their literature review, more than 125 complexity factors have been identified. These complexity factors have been categorized into Seven (7) dimensions (Project Context, Autonomy, Belonging, Connectivity, Diversity, Emergence, and Size). It has been found that the Project Context, Size and Autonomy have a big portion of the identified complexity factors (Bakhshi et al., 2016). Figure 6 illustrate the seven dimensions and its related major factors:

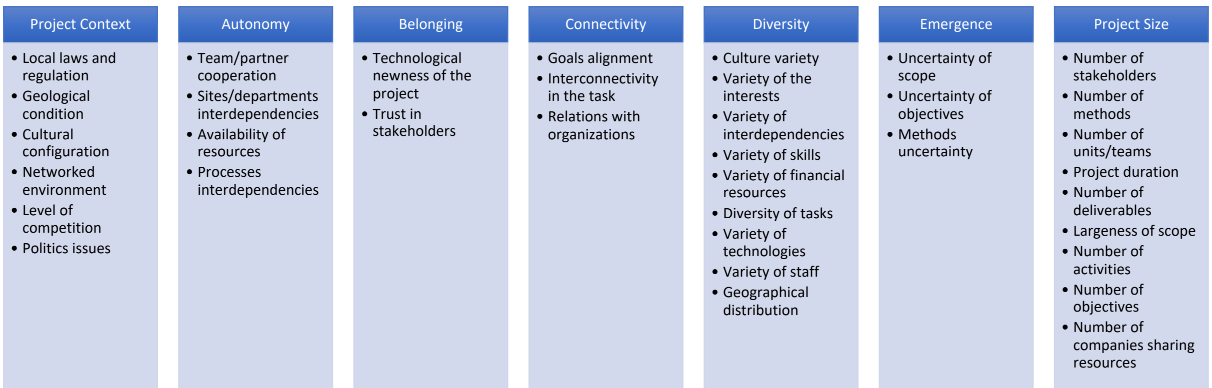

Figure 6: Project Complexity Factors (Bakhshi et al., 2016)

The Project Management Institute (PMI) in their published in-depth report "Navigating Complexity" they have listed the following most defining characteristics of complexity in the construction industry projects (Project Management Institute, 2013):

- Multiple stakeholders;
- Ambiguity of project features, resources, phases, etc.;
- Significant political/authority influences;
- Unknown project features, resources, phases, etc.;
- Dynamic (changing) project governance;
- Significant external influences;
- Use of a technology that is new to the organization;
- Use of a technology that has not yet been fully developed;
- Significant internal interpersonal or social influences;
- Highly regulated environment; and
- Project duration exceeds the cycle of relevant technologies.

The CII has conducted a research effort (RT 315) to identify some changes required in the planning and execution of mega-projects. In this research, they have used some criteria, in addition to the total project's cost, to identify the complexity level of mega-projects. these complexity criteria are as the following (Construction Industry Institute, 2015):

- Significant number of stakeholders;
- Large number of interfaces;
- Challenging project location;
- Inadequate supply of resources;
- Unfamiliar technology;
- Difficult regulatory constraints;
- Extensive infrastructure requirements;
- Geographically dispersed teams; and
- Significant political, economic, environmental, or social influence.

Mozaffari et al., (2012), utilized Delphi technique to identify the most important project complexity factors. After applying the Delphi technique on 47 complexity factors, 19 factors were identified as the most important factors to determine the project complexity level. These factors were categorized into Seven (7) groups as following; Environmental, Organizational, Objectives, Tasks, Stakeholders, Technological and Information systems. Table 3 shows the seven groups and its related factors (Mozaffari et al., 2012):

Group	Factors
Environmental	Environmental dependency
	Project environment stability
	Political effects
Organizational	Project team size
	Team interrelations
	Resource and skills availability
	Interdependence between parties
	Diversity of staff
Objectives	Interdependence of objectives
	Clarity of objectives
Tasks	Dependencies between tasks
	Uncertainties in scope
Stakeholders	Number of stakeholders
	Stakeholders perspectives
	Stakeholders interrelations
Technological	Technology diversity
	Interrelations between technological processes
Information systems	Variety of information system
	Interdependence of information system

Table 3: Factors of Project Complexity (Mozaffari et al., 2012)

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

As highlighted in the beginning of this paper, the Saudi construction industry considered one of the largest construction industries in the region. Currently, most of the projects in the Saudi construction industry are for re-building the Kingdome infrastructure which considered as complex projects due to many factors. Due to the complexity nature of re-building the Kingdome infrastructure, the constructability practices implementation become more important to prevent and/or mitigate the project risks that may affect the project success. Constructability can be one of the construction management tools that can be utilized to resolve and minimize the construction project complexity.

This part of the paper will discuss the research methodology that was followed to study the impact of the constructability implementation in complex projects in the Saudi construction industry. The required data, the data collecting tools that will be utilized in this study and data analysis are discussed in Section 3.2, 3.3 and Section 4.3 respectively.

3.2 Required Data

The requited data to achieve the main aim and objective of this study which is to investigate the impact of implementing constructability practices on the private and semi-government complex industrial projects in the Saudi construction industry are as the following:

- The level of constructability implementation among the private and semi-government owners;
- The complexity criteria that the private and semi-government owners use to measure the level of complexity for their projects;
- The techniques that the that the private and semi-government owners use to implement constructability for their complex industrial construction projects;
- The constructability implementation barriers for complex industrial projects among the private and semi-government owners;
- The constructability implementation benefits for complex industrial projects among the private and semi-government owners; and
- The success factors for implementing constructability for complex industrial projects among the private and semi-government owners.

3.3 Data Collection

This part of the paper outlines the research methodology that was followed to collect the required data. In this study, two data collection methods were conducted to achieve the study objective which highlighted in Section 1.3. The first method of collecting data is the questionnaire. The second method of collecting data is conducting a case study.

3.3.1 The questionnaire

The questionnaire containing close-ended questions with allowing the participants for more elaboration and/or specifying other answers is developed to collect the required data highlighted in Section 3.2 for this study. This questionnaire consists of three sections. The first section contains questions seeking information on the characteristics of the participants such as; level of education, experience, familiarity with the constructability practices and professional certifications & memberships. The second section contains questions seeking information on the characteristics of the participant’s organization such as; experience in the Saudi construction industry, types and volume of the executed projects, contractual obligation used, and delivery system utilized. The third section, which is considered the main section of the questionnaire, contains questions to identify, measure and examine the techniques, benefits, barriers, success factors of implementing the constructability practices among the complex industrial projects in the Saudi construction industry. In addition, this section of the questionnaire contains questions to measure and examine the impact of the constructability implementation on the project complexity level. A cover letter is also developed to inform the questionnaire's participants about the study and the objectives of this questionnaire. Both the developed questionnaire and the cover letter will be sent via e-mail and/or delivered hand by hand to the targeted participants. The cover letter along with the questionnaire is found in the appendices (Appendix- A).

3.3.1.1 the questionnaire participants

The targeted participants were the Project Managers, Sr. Project Engineers, Project Engineers who represents the owner (private and semi-government) and/or the major engineering, consultants and construction firms in executing complex industrial construction projects in the Saudi construction industry

3.3.1.2 population and sampling size

The sample size required for the questionnaire to answer the first research question will be determined using the following formula (Kish, 1995):

$$n_o = \frac{p * q}{v^2}$$

$$n = \frac{n_o}{1 + \frac{n_o}{N}}$$

Where:

n_o : Sample size's first estimate.

p : The proportion of the characteristic being measured in the target population.

q : $1 - p$

v : The maximum allowable percentage of standard error.

N: The population size.

n : The sample size.

To obtain the maximum sample size, the value for both "p" and "q" will be taken as 0.5. The maximum standard error allowed in this study will be taken as 10% ($v = 0.1$).

3.3.2 The case study

To achieve the main aim and objective of this study, a case study was selected and analyzed explanatorily in depth to examine the current constructability practices for private can semi-government complex projects in the Saudi construction industry.

One of the advantages of selecting the case study as a method of data collection is the opportunity to be exposed to many different sources of data (Yin, 2009). Reviewing the project documents and interviewing the project's key personnel will be conducted as part of this study.

Reviewing the project's documents:

In this part of the study, the data collection process was started with reviewing the project documents, including the review of the project categorization procedures, project requirements identification and constructability implementation practices at corporate and project level. After reviewing the documents and gaining a better understanding about the constructability practices for complex projects, the interviews with the project's key personnel commenced.

Interviewing the project's key personnel:

In this part of the study, a number of face to face interviews will be conducted with the project's key personnel including Project Managers, Sr. Project Engineers, Project Engineers and individuals who were involved in categorizing the project and/or involved in the constructability implementation.

3.4 Data Analysis

In this study, two methods of data analysis were utilized to achieve the main aim and objective of the study. First, the descriptive analysis which was utilized to count the frequencies of some responses, calculate the proportion and present the results in tables and graphs for all the questions in the questionnaire. Secound, the statistical analysis which was utilized to determine the independence between two variables by statistical significance.

CHAPTER 4: DATA ANALYSIS AND DISSCUTION

4.1 Introduction

This chapter will analyze and discuss the data that has been collected by following the research methodology highlighted in Chapter Three (3). This part of the study can be divided into Two (2) main parts. The First part will analyze and discuss the data collected thru the questionnaire that has been distributed among Owners, Designers/Consultants and Constructors firms executing complex industrial projects in the Saudi construction industry. The Second part will discuss the selected case study of a construction industrial project, located in the Eastern Province of the Kingdom of Saudi Arabia, where constructability practices have been implemented through the project’s life-cycle. The results obtained by conducting questionnaire and case study will be analyzed taking into consideration beforehand represented the previous studies that have been highlighted in Chapter Two (2). This chapter will achieve the study’s main aim and objective which is to investigate the impact of implementing constructability practices on the private and semi-government complex industrial projects in the Saudi construction industry.

4.2 The Questionnaire

4.2.1 Introduction

This part will discuss and analyze the distributed questionnaire among the owner, major designer/consultant and constructor firms executing complex industrial construction projects located in the Eastern Province of the Kingdom of Saudi Arabia. After exploring the construction industry at the Eastern Province of the Kingdom, it was found that total of Two (2) semi-government, Five (5) major designer/consultant and Forty (40) major constructor firms who are executing complex industrial construction projects in this part of the Kingdome. Due to the limited number of owner and designer/consultant firms, the questionnaire was distributed to all of the owner and designer/consultant firms. On the other hand, due to the large number of constructor firms, the sampling method highlighted in Section 3.3.1.2 was applied. However, the questionnaire was also distributed to all of the identified constructor firms. An approved list of the constructor firms executing complex industrial construction projects was obtained from one of the owner firms. All of the identified owner and designer/consultant firms have participated in this study by providing their feedback through the distributed questionnaire. Moreover, out of the Forty (40) major constructor firms only Twenty-five (25) firms have participated in this study by providing their feedback through the distributed questionnaire.

$n_o = 40$

$n = 15.4 \approx 16$ (40 %)

The response rate of the identified constructor firms was (62.5%) which is higher than the required response rate determined by the sampling method (40%). In this exercise of data collection through the questionnaire survey method, (37.5%) of the constructor firms did not participate in this study. Therefore, of the total 47 questionnaires sent to different owner, designer/consultant and constructor firms, 32 (68.1%) response were received. Only Two (2) of the received questionnaires have been excluded due to unfamiliarity of the respondent with the constructability concepts and practices. The received data was carefully read and, in some cases, the respondents were contacted for certain clarifications.

4.2.2 Description of the results

The presentation of the results will be in three major parts. The First Part will analyze and present the data collected from questions seeking information on the characteristics of the participants such as; level of education, experience, familiarity with the constructability practices and professional certifications & memberships. The results of this part were acquired from questions in Section_1 of the questionnaire. The Second Part will analyze and present the data collected from questions seeking information on the characteristics of the participant's organization such as; experience in the Saudi construction industry, types and volume of the executed projects, contractual obligation used, and delivery system utilized. The results of this part were acquired from questions in Section_2 of the questionnaire. The Third Part will analyze and present the data collected from questions seeking to identify, measure and examine the techniques, benefits, barriers, success factors of implementing the constructability practices among the complex industrial projects in the Saudi construction industry. In addition, this part will analyze and present the data collected from questions seeking to measure and examine the impact of the constructability implementation on the project complexity level. The results of this part were acquired from questions in Section_3 of the questionnaire.

4.2.2.1 part_1: characteristics of the respondents

The participants have different job titles in their organizations, where the majority of the participants (33%) currently works as Project Managers, (24%) of the participants are Sr. Project Engineers and (23%) are Project Engineers. Moreover, (20%) of the participants are working as Constructability Specialists/Facilitators in their organizations. Figure 7 and Figure 8 summarizes the participants job titles.

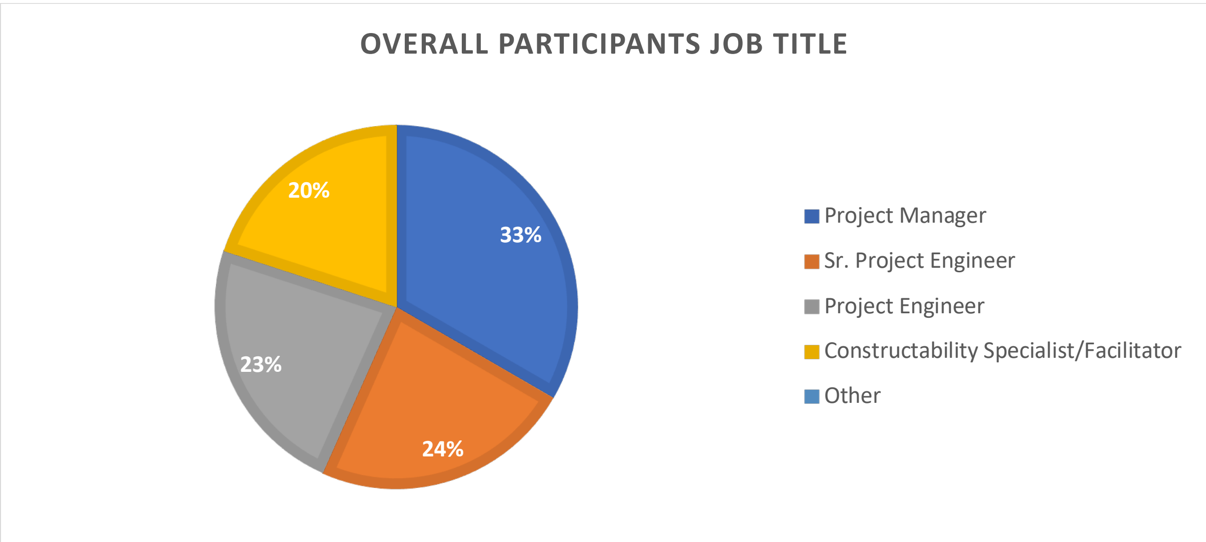

Figure 7: Overall Participants Job Title

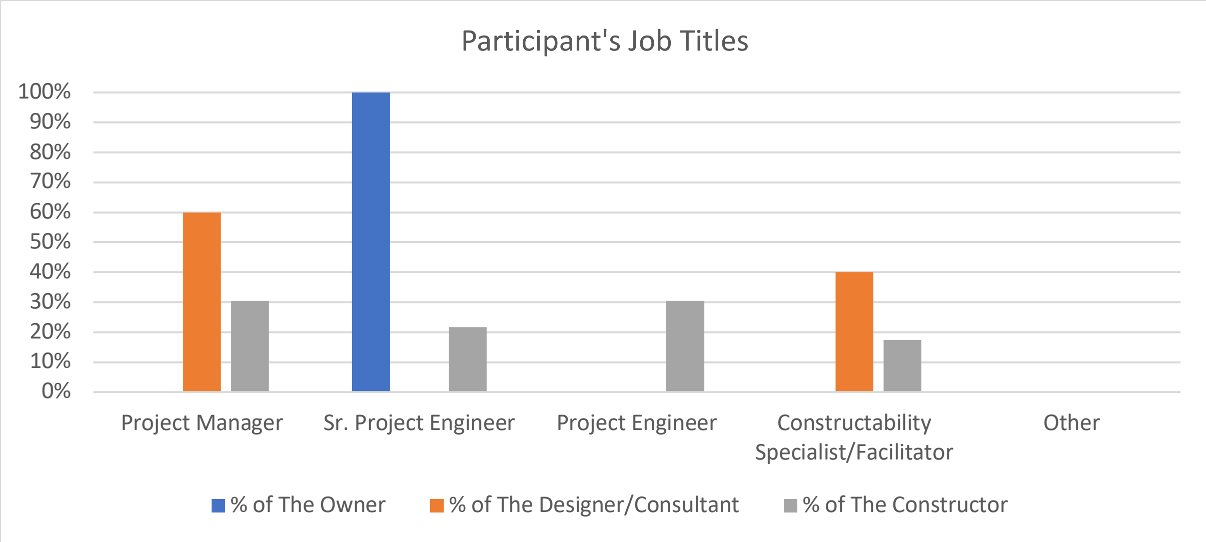

Figure 8: Participant's Job Titles

Furthermore, the participants have also different level of experience in the business of construction projects, where the majority of the participants (53%) have more than Fifteen (15) years of experience, followed by the participants who have Ten (10) to less than Fifteen (15) years of experiences which represents (30%) of the participants and (17%) of the participants have less than Ten (10) years of experience in the business of construction projects. Figure 9 and Figure 10 summarizes the participants experiences.

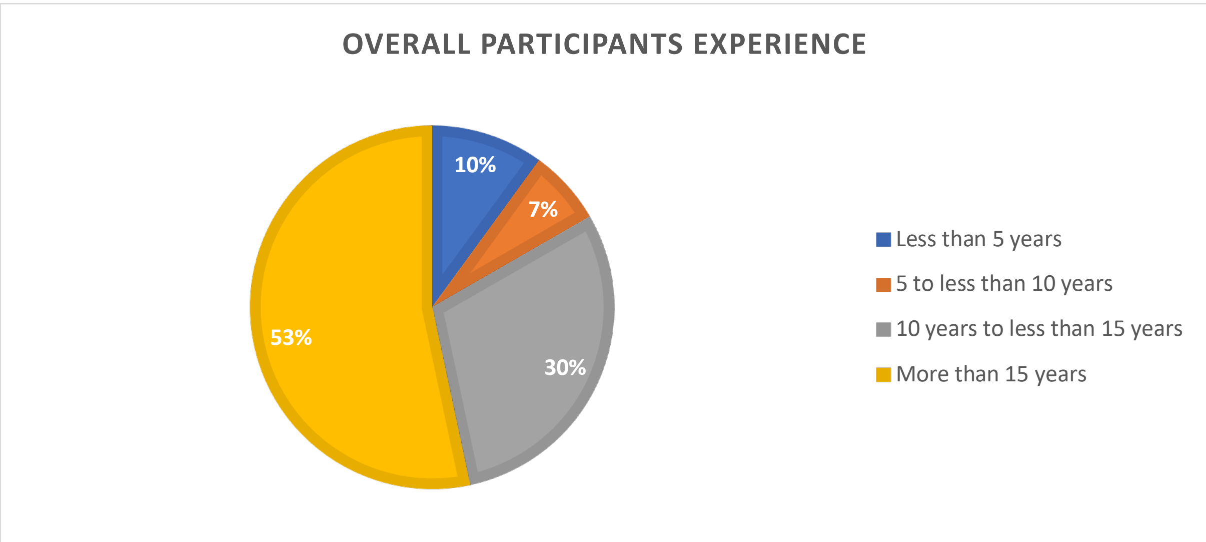

Figure 9: Overall Participants Experience

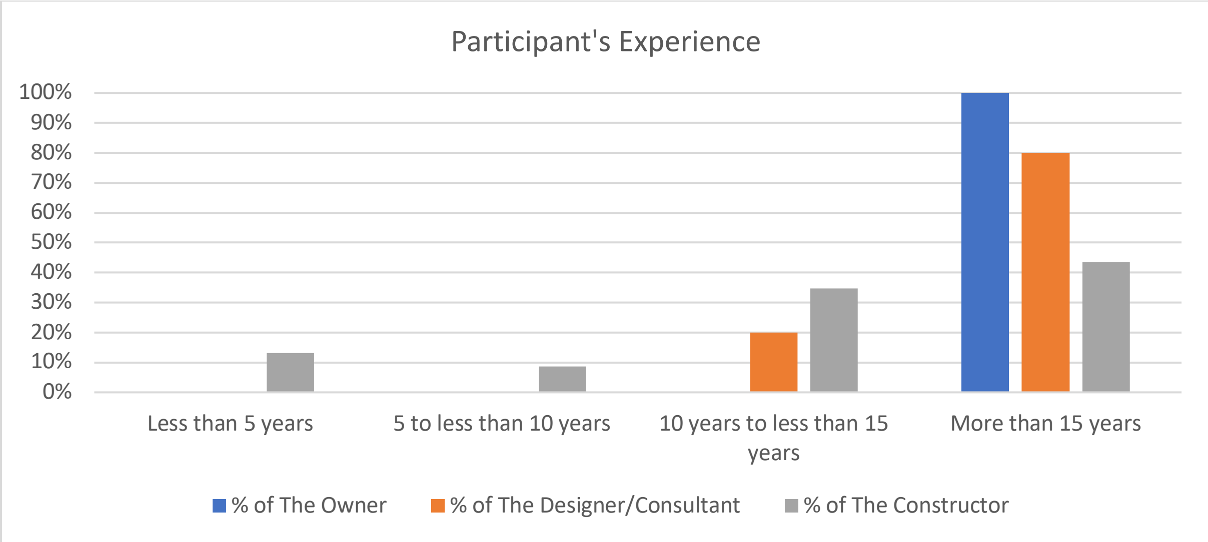

Figure 10: Participant's Experience

Moreover, the participants have different level of education in various engineering disciplines such as civil, mechanical, electrical, chemical and industrial engineering. Figure 11 and Figure 12 summarizes the participants degree disciplines.

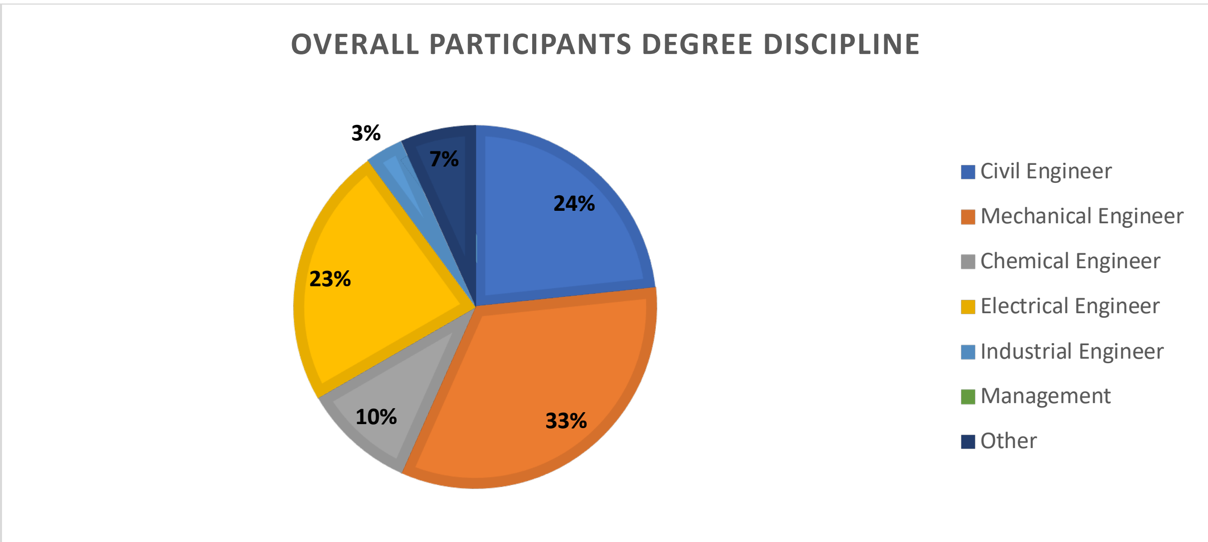

Figure 11: Overall Participants Degree Discipline

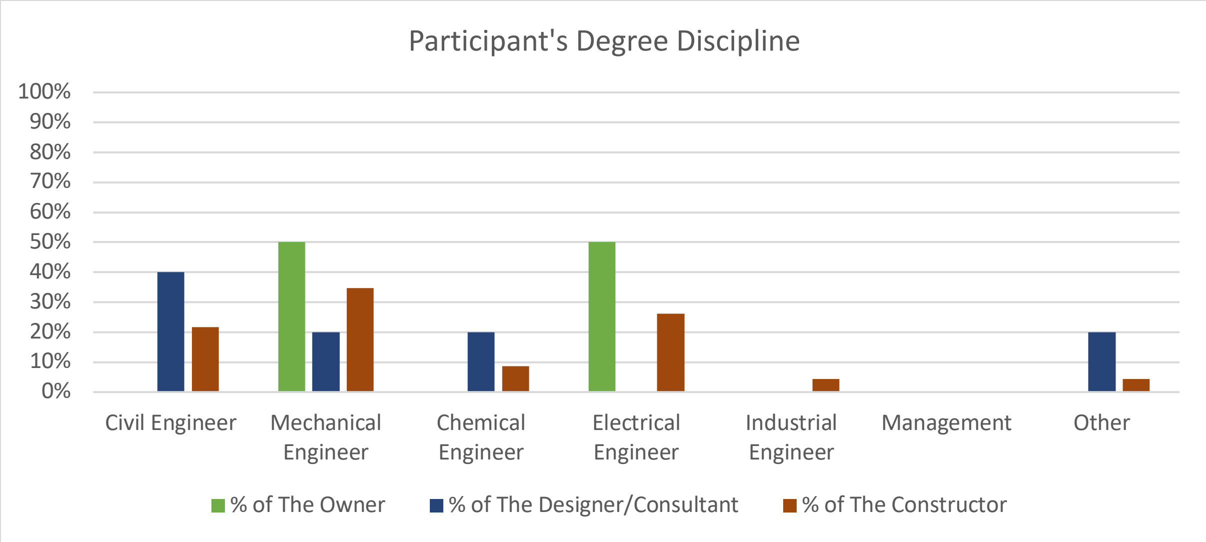

Figure 12: Participant's Degree Discipline

The majority of the participants (44%) have bachelor's degree, followed by the participants (43%) who have master's degree and (13%) of the participants have PhD. Figure 13 and Figure 14 summarizes the participants level of education.

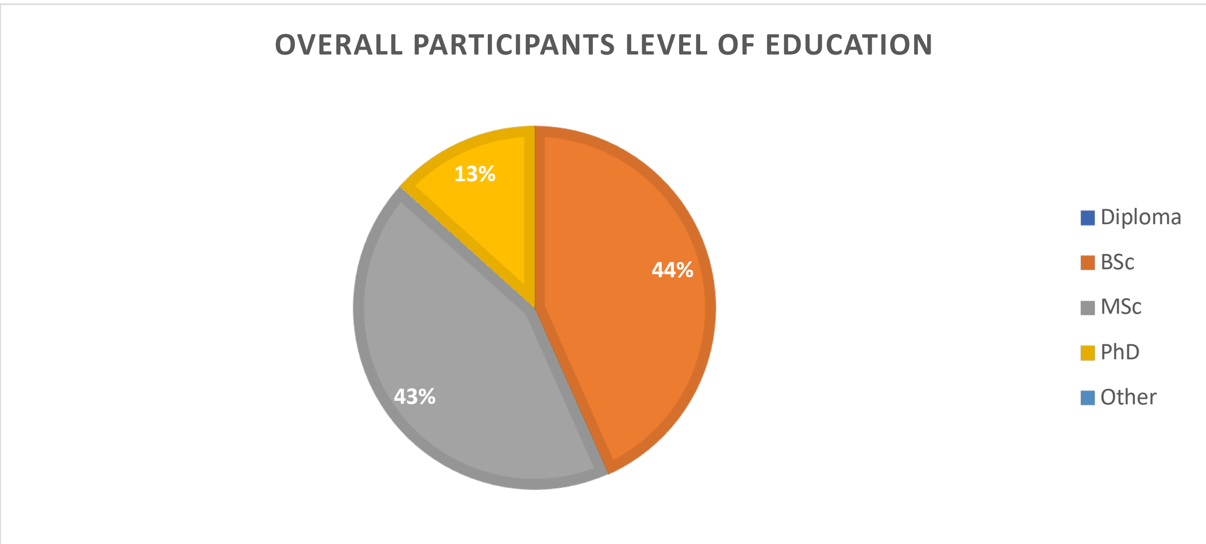

Figure 13: Overall Participants Level of Education

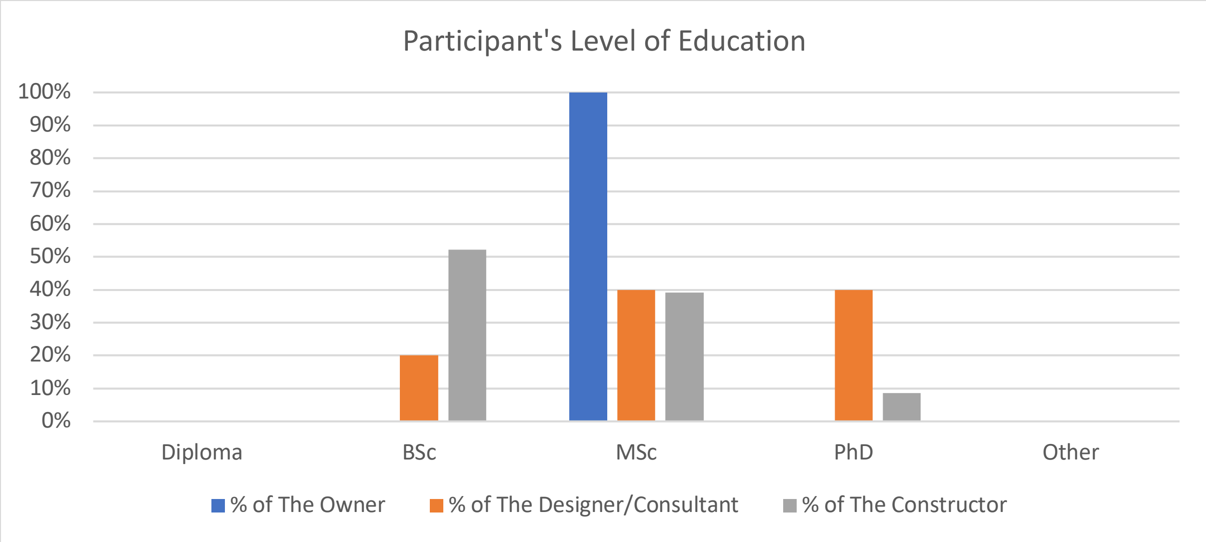

Figure 14: Participant's Level of Education

The participants have various of professional certificates and they are members of different professional associations. The majority of the participants (57%) are Project Management Professional (PMP) certified. Figure 15 and Figure 16 summarizes the participants professional certificates.

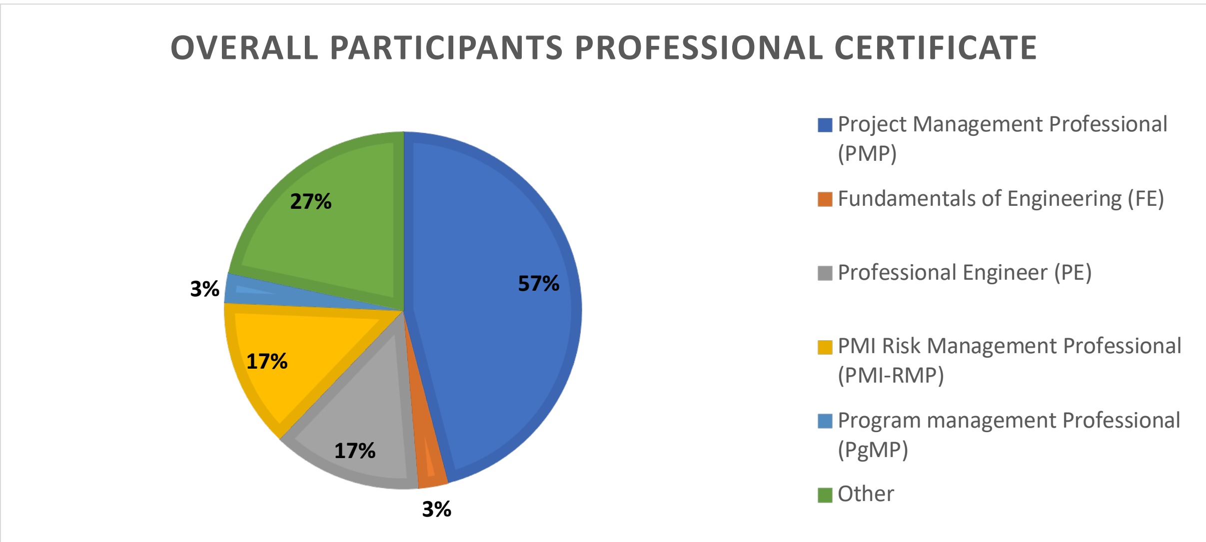

Figure 15: Overall Participants Professional Certificate

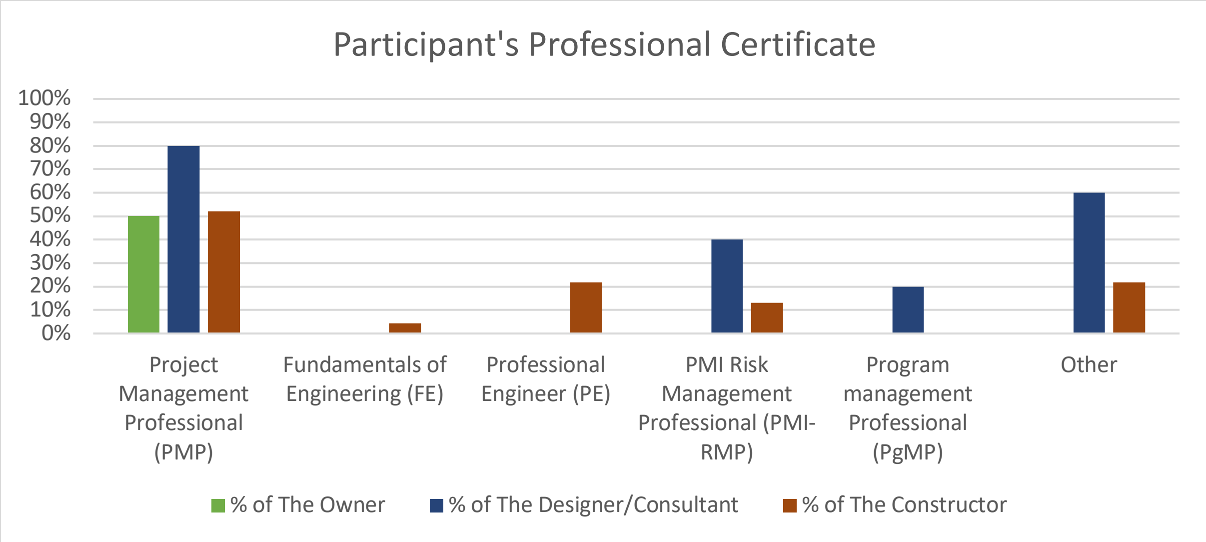

Figure 16: Participant's Professional Certificate

Moreover, more than half of the participants (60%) are members in the Project Management Institute (PMI). Figure 17 and Figure 18 summarizes the participants membership in professional association.

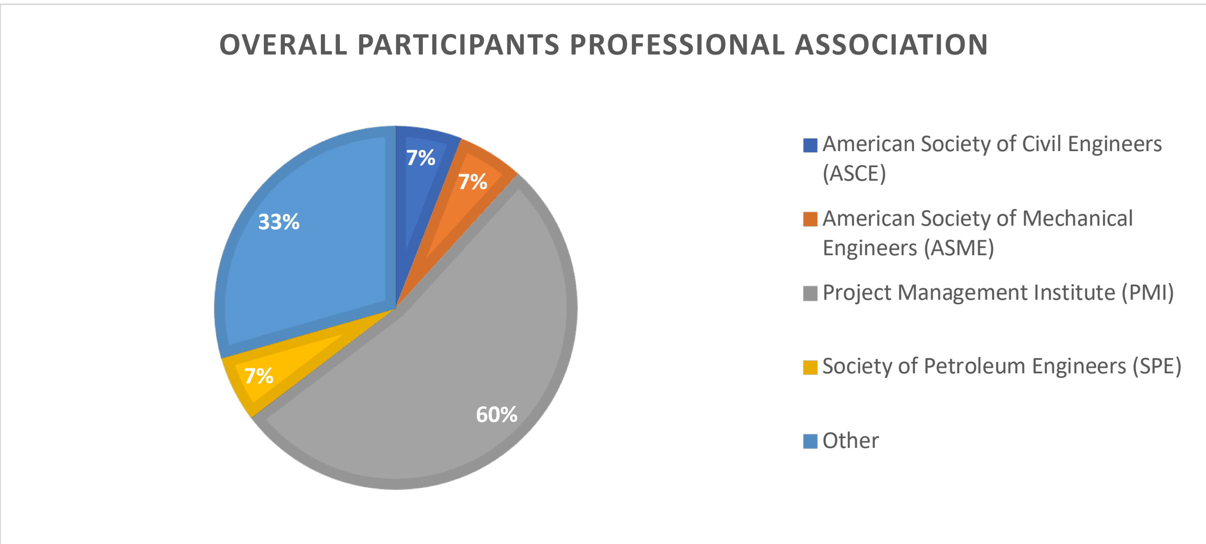

Figure 17: Overall Participants Professional Association

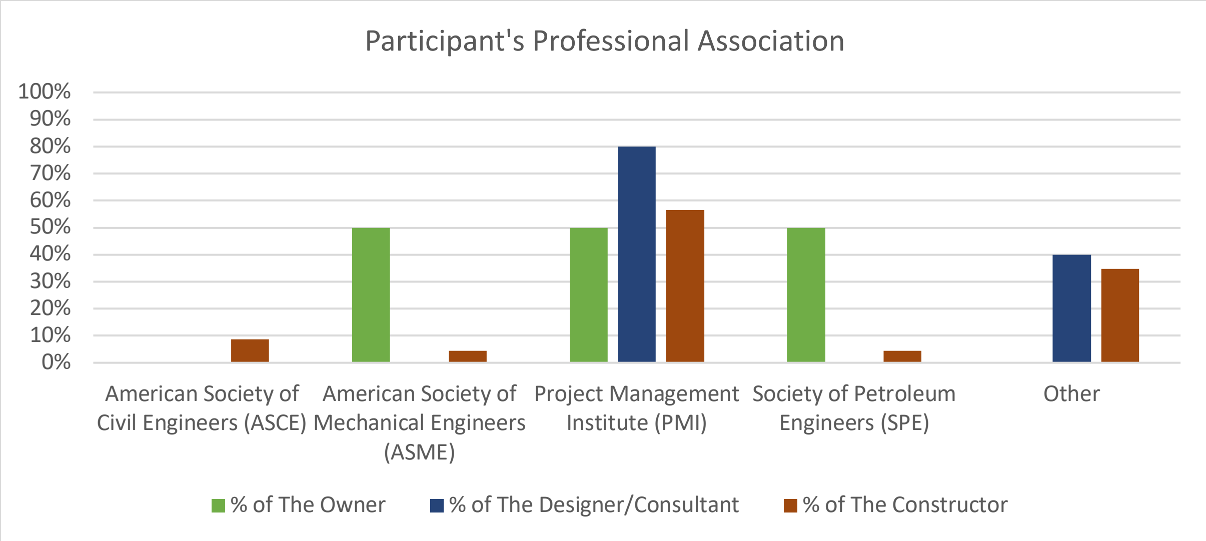

Figure 18: Participant's Professional Association

The participants have executed different number of construction projects. The majority of the participants (63%) have executed more than Six (6) construction projects, followed by the participants (17%) who have executed Two (2) to less than Four (4) construction projects and (10%) of the participants have executed Four (4) to less than Two (2) construction projects as well as participants have executed less than Two (2) construction projects. Figure 19 and Figure 20 summarizes the number of projects that the participants were involved in.

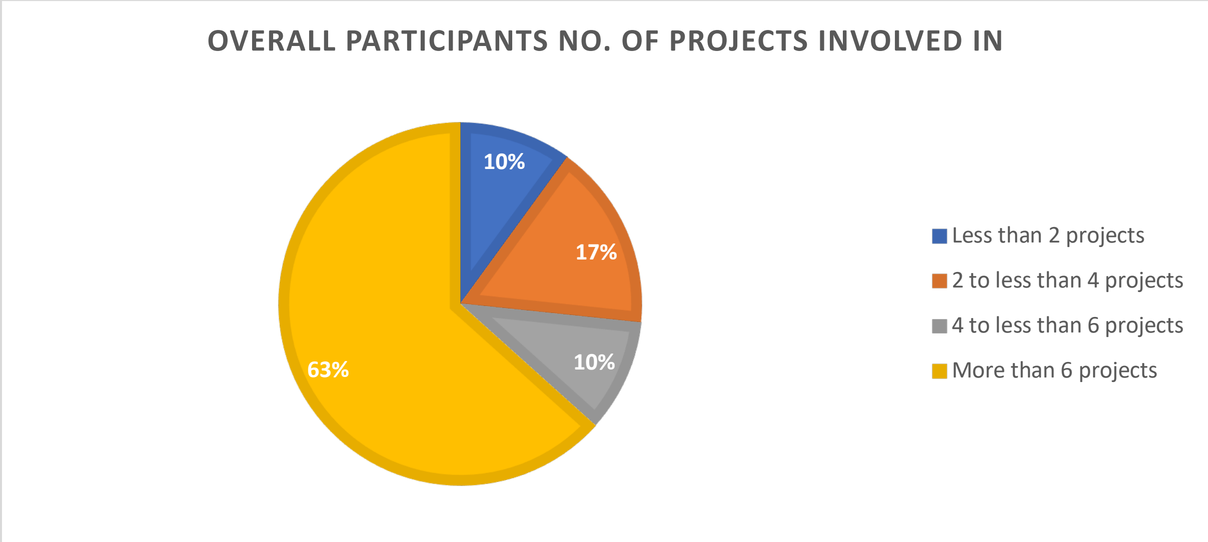

Figure 19: Overall Participants No. of Projects Involved in

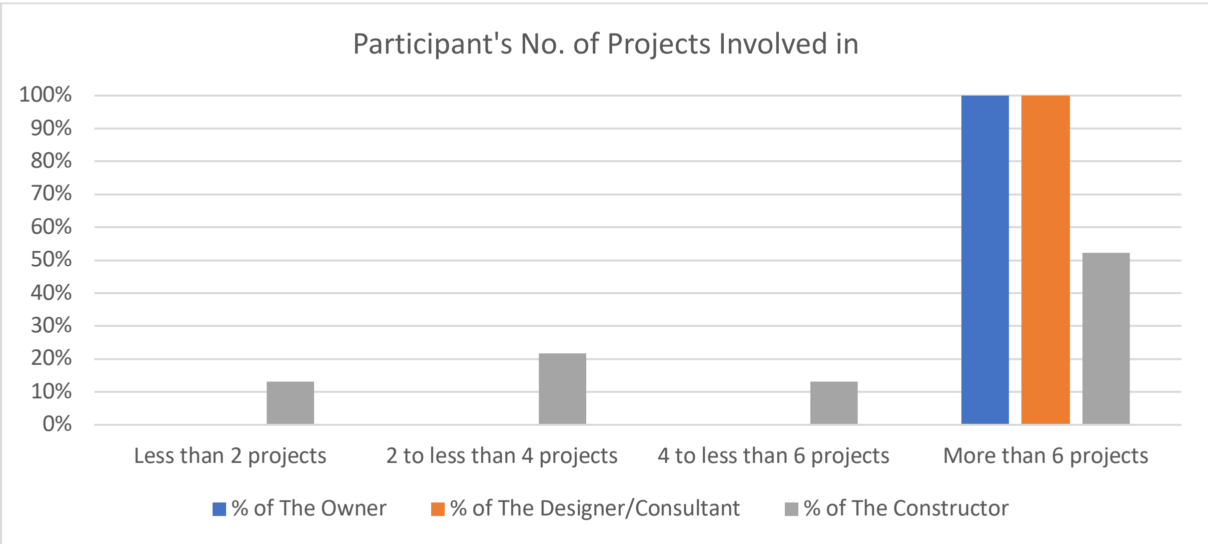

Figure 20: Participant's No. of Projects Involved in

The participants have involved in different number of constructability practices. The majority of the participants (57%) have participated in more than Six (6) constructability practices, followed by the participants (20%) who have participated in Two (2) to less than Four (4) constructability practices, (13%) of the participants have participated in less than Two (2) constructability practices and only (10%) of the participants have participated in Four (4) to less than Six (6) constructability practices.

Figure 21 and Figure 22 summarizes the number of constructability practices that the participants were involved in.

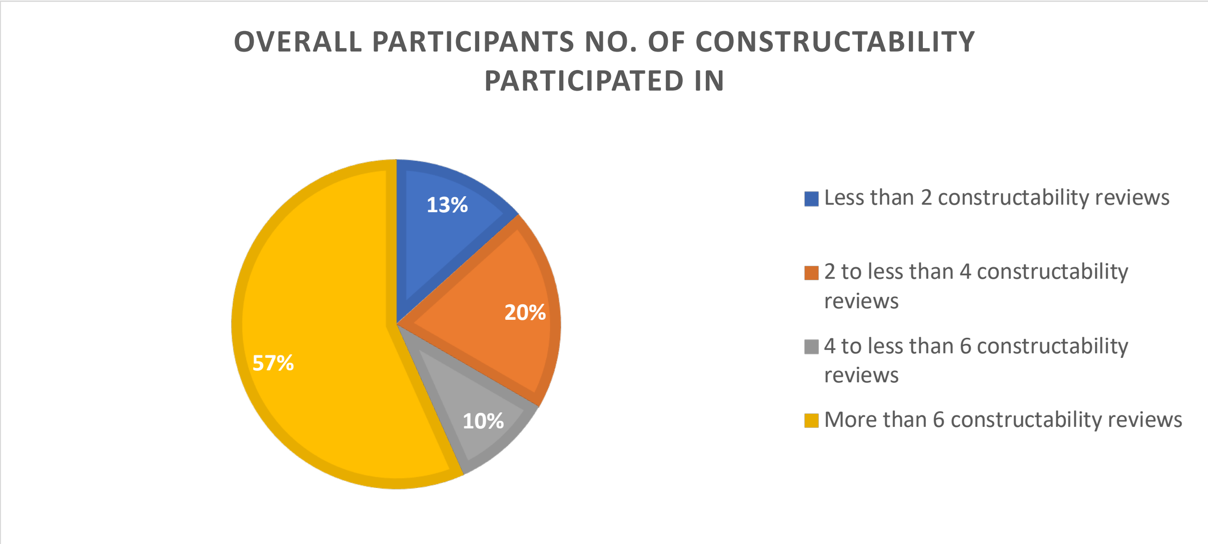

Figure 21: Overall Participants No. of Constructability Participated in

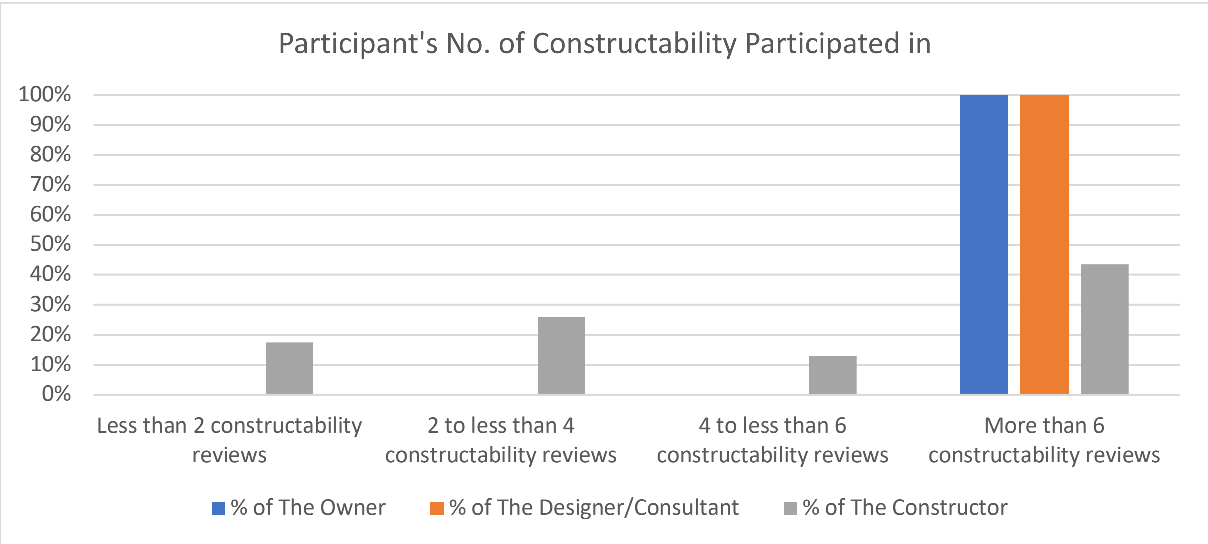

Figure 22: Participant's No. of Constructability Participated in

The participants have received different methods of constructability training. The majority of the participants (53%) have the opportunity to have on the job training, followed by the participants (43%) learned about the constructability concept and practices through self-training. Moreover, (33%) of the participants was enrolled in training courses conducted by their organizations. Figure 23 and Figure 24 summarizes the constructability training methods received by the participants.

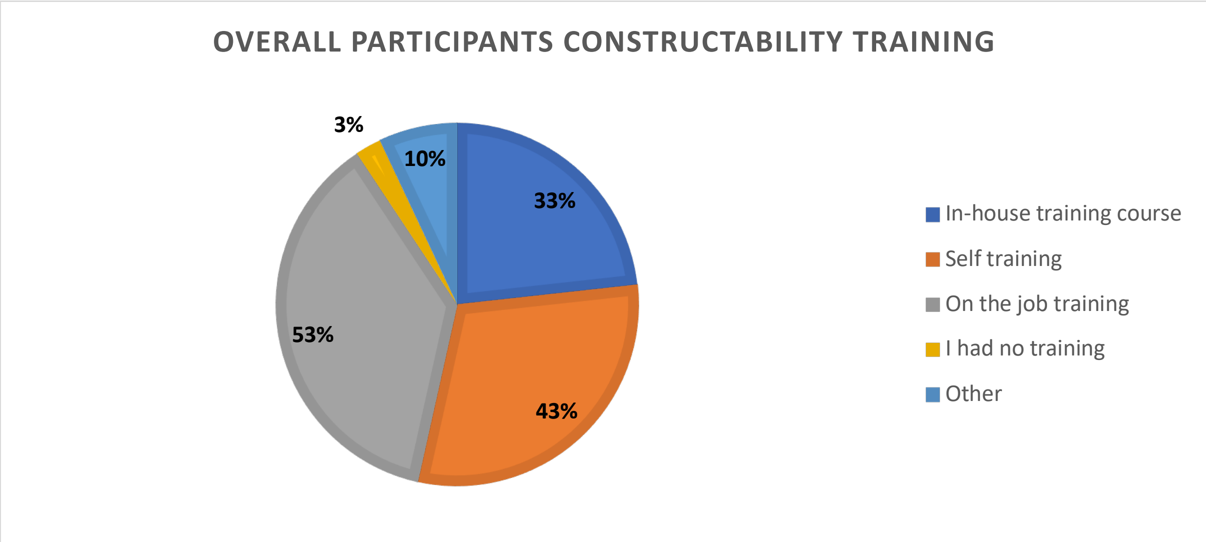

Figure 23: Overall Participants Constructability Training

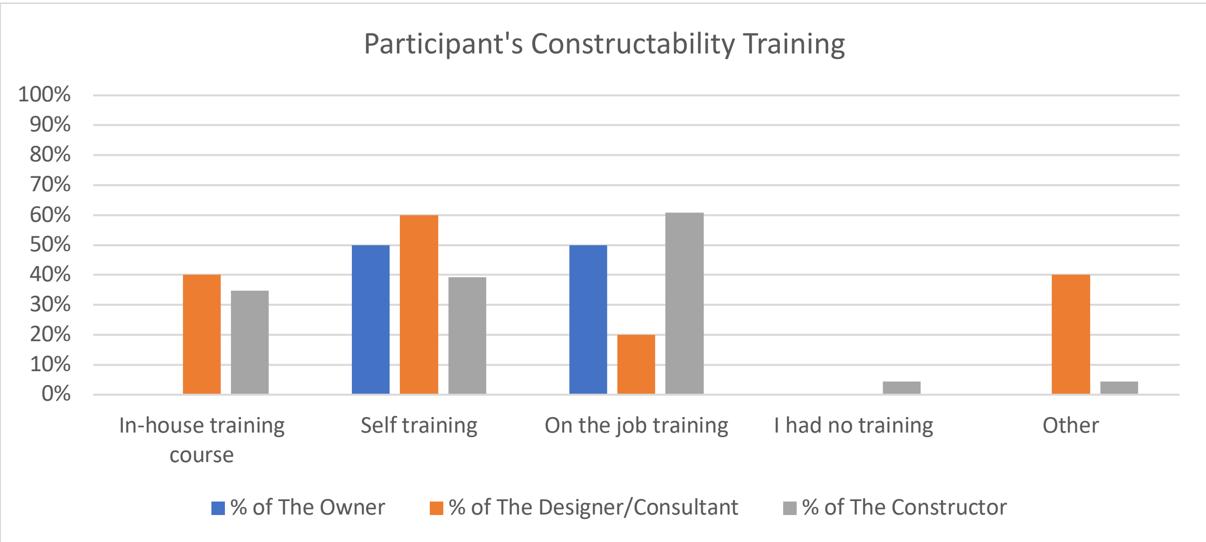

Figure 24: Participant's Constructability Training

The participants have different level of familiarity with the constructability concept and practices. The majority of the participants (47%) answered that the constructability concept is well-known to them, followed by the participants (23%) with average level of familiarity about the constructability concept. Moreover, (20%) of the participants indicated that the constructability concept and practices is very well-known to them. Figure 25 and Figure 26 summarizes the participants level of familiarity with the constructability concept and practices.

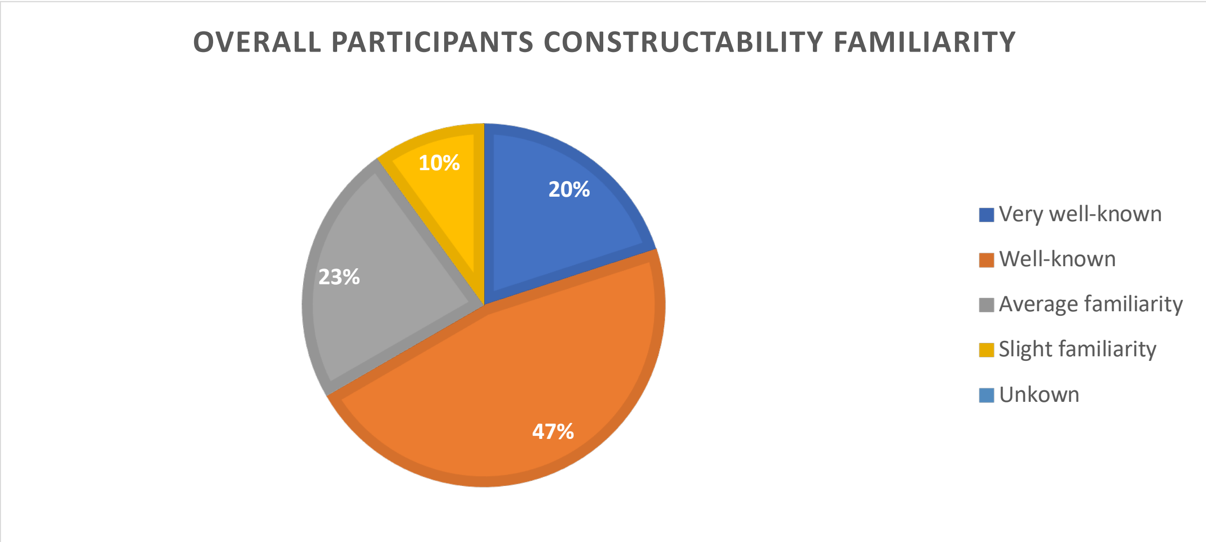

Figure 25: Overall Participants Constructability Familiarity

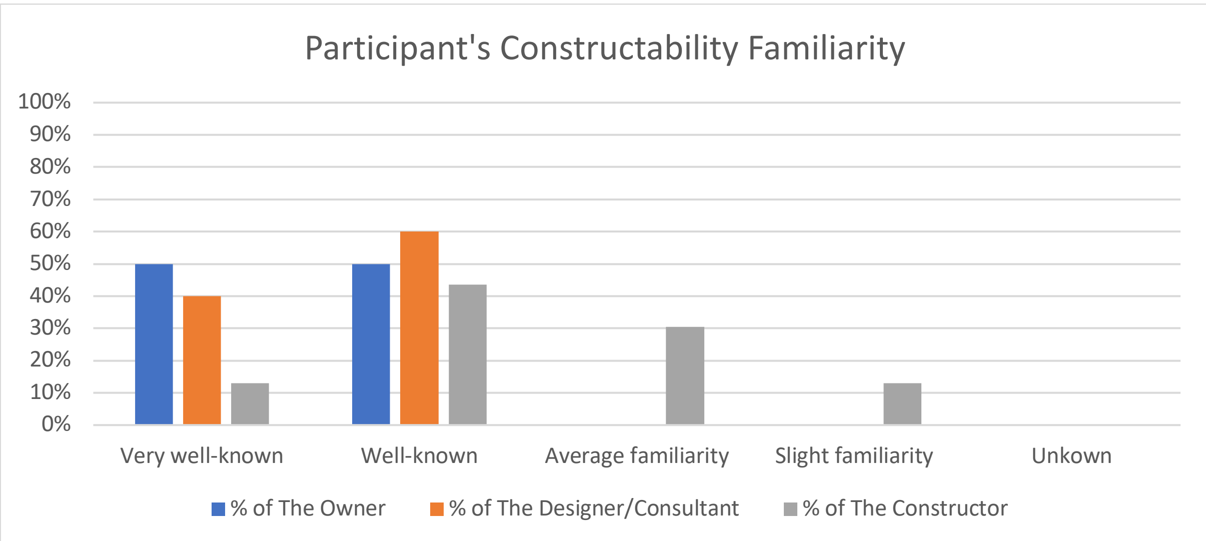

Figure 26: Participant's Constructability Familiarity

With the above-mentioned data collected from questions seeking information on the characteristics of the participants acquired from questions in Section_1 of the questionnaire, it has been concluded that the questionnaire participants can be considered as qualified and trustworthy source of information.

4.2.2.2 part _2: characteristics of the organization

The participants organizations have various range of experience in the business of construction projects, where the majority of the participated organizations (46%) have more than Twenty-five (25) years of experience, followed by the organizations who have less than Ten (10) years of experiences which represents (27%) of the participated organizations and (10%) of the organizations have Ten (10) to less than Fifteen (15) years of experience in the business of construction projects as well as organizations with Twenty (20) to less than Twenty-five (25) years of experience. Figure 27 and Figure 28 summarizes the participated organizations experience.

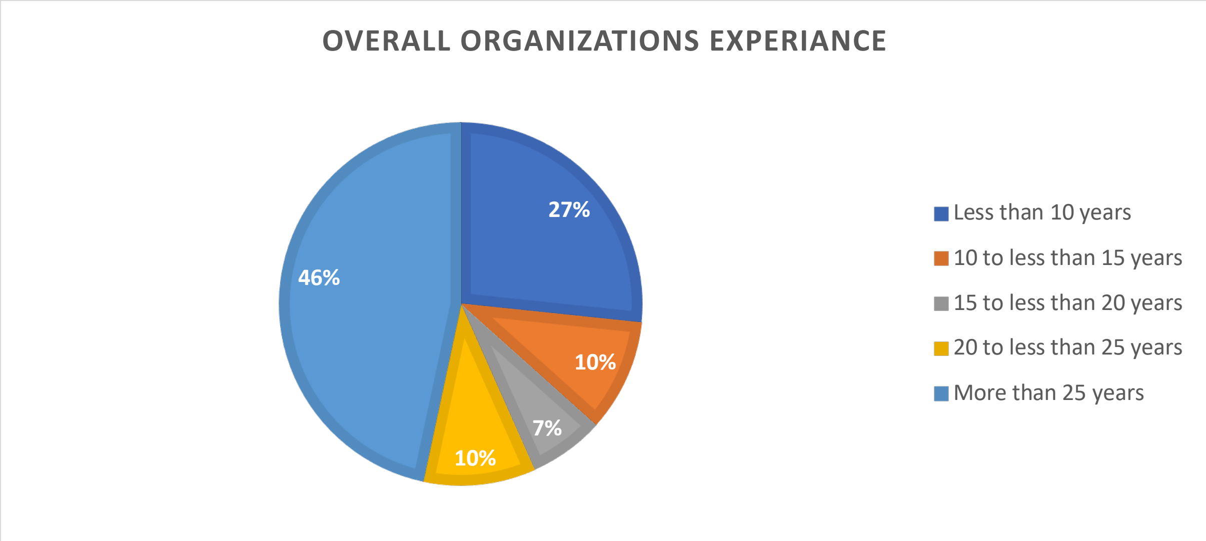

Figure 27: Overall Organizations Experience

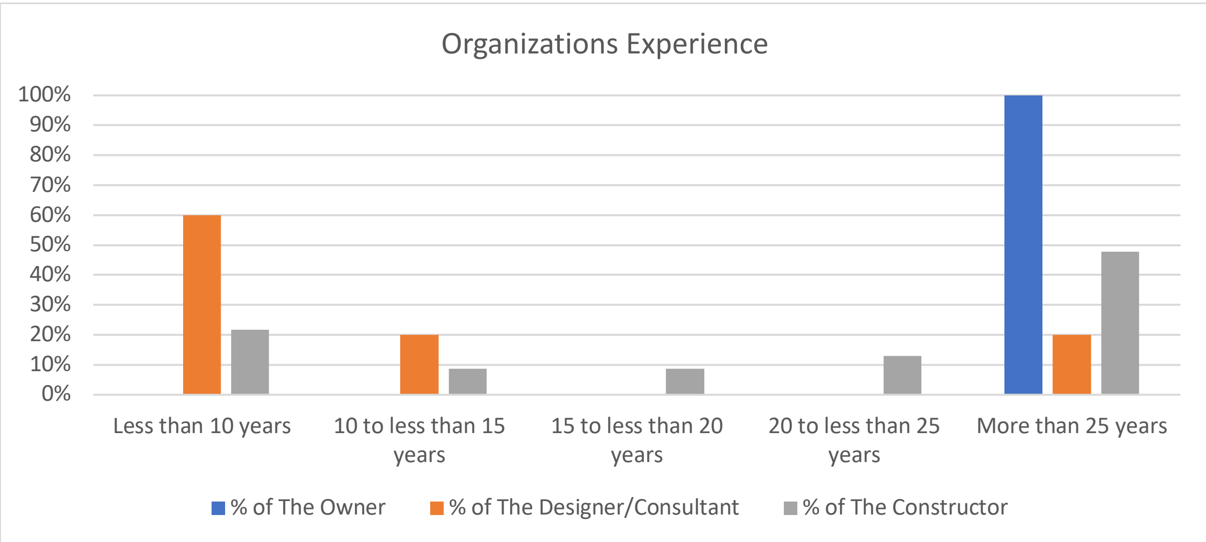

Figure 28: Organizations Experience

The number of complex construction projects executed annually by the participated organizations is ranged from less than Two (2) to more than Forty (40) construction project per year, where the majority of the participated organizations (40%) executes Two (2) to less than Ten (10) complex construction projects per year, followed by (23%) of the organizations executes more than Forty (40) projects and (13%) of the organizations executes Twenty (20) to less than Forty (40) complex construction projects per year. Figure 29 and Figure 30 summarizes the number of complex construction projects executed annually by the participated organizations.

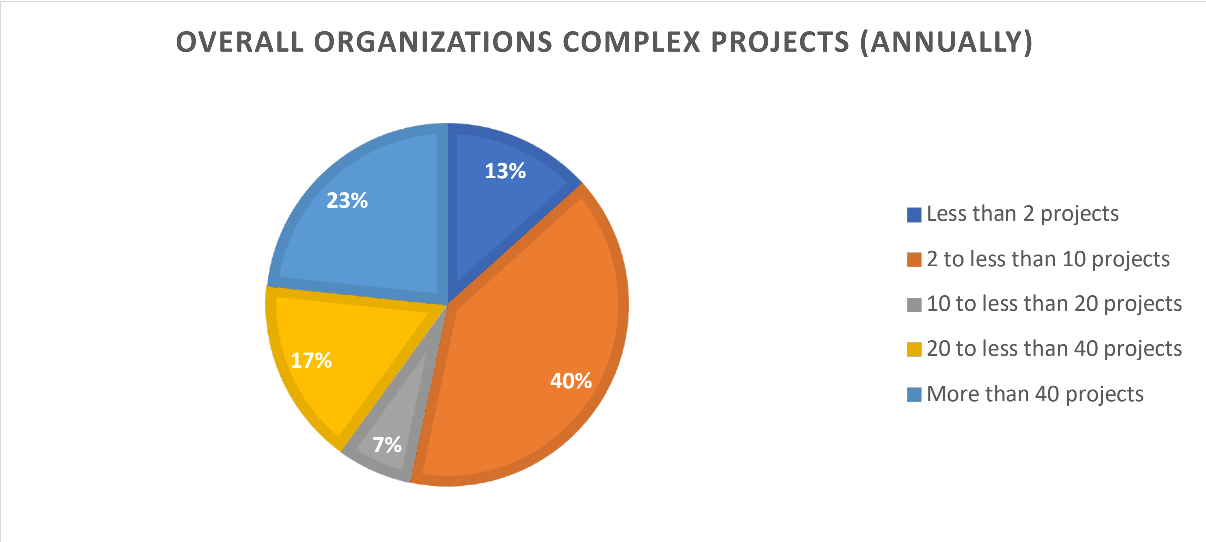

Figure 29: Overall Organizations Complex projects (annually)

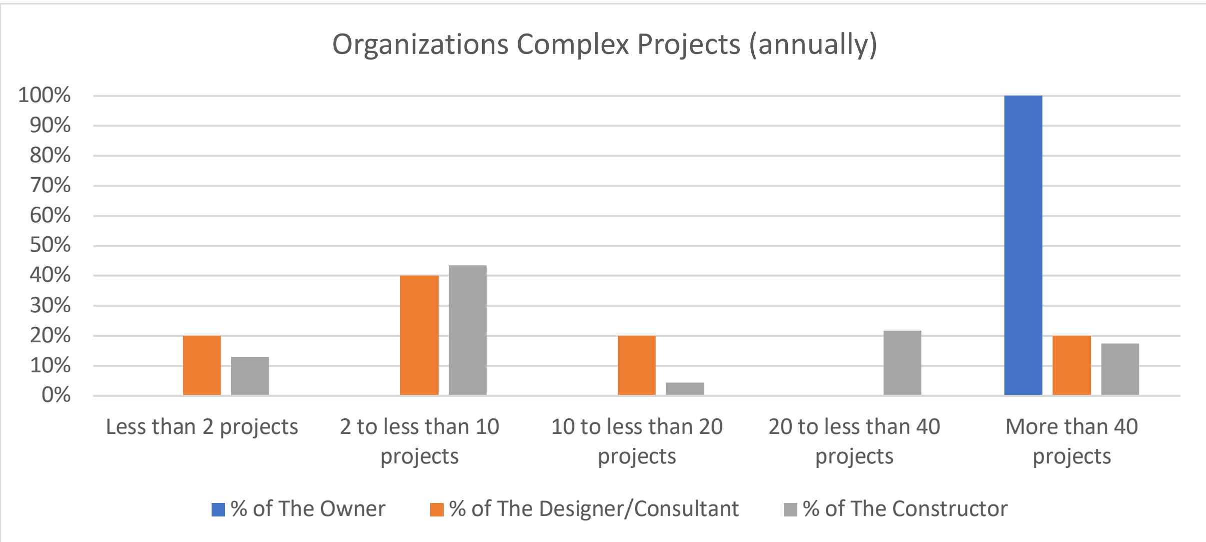

Figure 30: Organizations Complex Projects (annually)

Furthermore, the reposes were covered all complex construction project categories of project types, budget values, delivery systems and contract types. The owner's participants indicated that, on average, (63%) of their complex construction projects are industrial (process oriented) type of projects, followed by (25%) of their complex construction projects are considered general buildings (commercial, housing, etc.) type of projects and only (13%) are heavy civil work (infrastructure) type of projects. Moreover, the owner's participants also indicated that, on average, (44%) of their complex construction projects are with budget value of 200 to less than 500 million U.S dollar, (22%) with budget value of 100 to less than 200 million U.S dollar as well as 50 to less than 100 million U.S dollar and only (11%) of their complex construction projects with budget value of less than 50 million U.S dollar. Most of the owner's complex construction projects (62.5%) are executed with fixed price contract type and the remaining (37.5%) are executed with unite rate contract type. Furthermore, the owner's participants also indicated that the majority of their complex construction projects are executed equally with Two (2) different project delivery systems which are the Traditional (Design-Bid-Build) and Turnkey project delivery systems.

On the other hand, the designer's/consultant's participants indicated that, on average, (55%) of their complex construction projects are industrial (process oriented) type of projects, followed by (25%) of their complex construction projects are considered heavy civil work (infrastructure) type of projects and (20%) are general buildings (commercial, housing, etc.) type of projects. Moreover, the designer's/consultant's participants also indicated that, on average, (35%) of their complex construction projects are with budget value of 50 to less than 100 million U.S dollar, followed by (25%) with budget value of 100 to less than 200 million U.S dollar as well as projects will budget value of more than 500 million U.S dollar, (10%) and (5%) of their complex construction projects are with budget value of 200 to less than

500 and less than 50 million U.S dollar respectively. Most of the designer's/consultant's complex construction projects (60%) are executed with fixed price contract type and the remaining (40%) are executed with unite rate contract type. Furthermore, the designer's/consultant's participants also indicated that their complex construction projects are executed with different types of project delivery systems such as; Traditional (Design-Bid-Build), Turnkey and Design-Build.

On the other hand, the constructor's participants indicated that the majority of their complex construction projects (70%) are industrial (process oriented) type of projects. Moreover, the constructor's participants also indicated that, on average, (27%) of their complex construction projects are with budget value of 50 to less than 100 million U.S dollar, followed by (24%) with budget value of more than 500 million U.S dollar, (22%) with budget value of less than 50 million U.S dollar, (17%) with budget value of 200 to less than 500 million U.S dollar and (10%) with budget value of 100 to less than 200 million U.S dollar. Most of the constructor's complex construction projects (53%) are executed with fixed price contract type, followed by (32%) are executed with unite rate contract type, only (8%) of the constructor's complex construction projects are executed with cost plus contract type as well as another contract types. Furthermore, the constructor's participants also indicated that their complex construction projects are executed with different types of project delivery systems such as; Traditional (Design-Bid-Build), Turnkey, Design-Build and other project delivery systems. The distribution of the participants in terms of their complex construction project's types, budget values, delivery systems and contract types are summarized in Figure 31, 32, 33 and Figure 34 respectively.

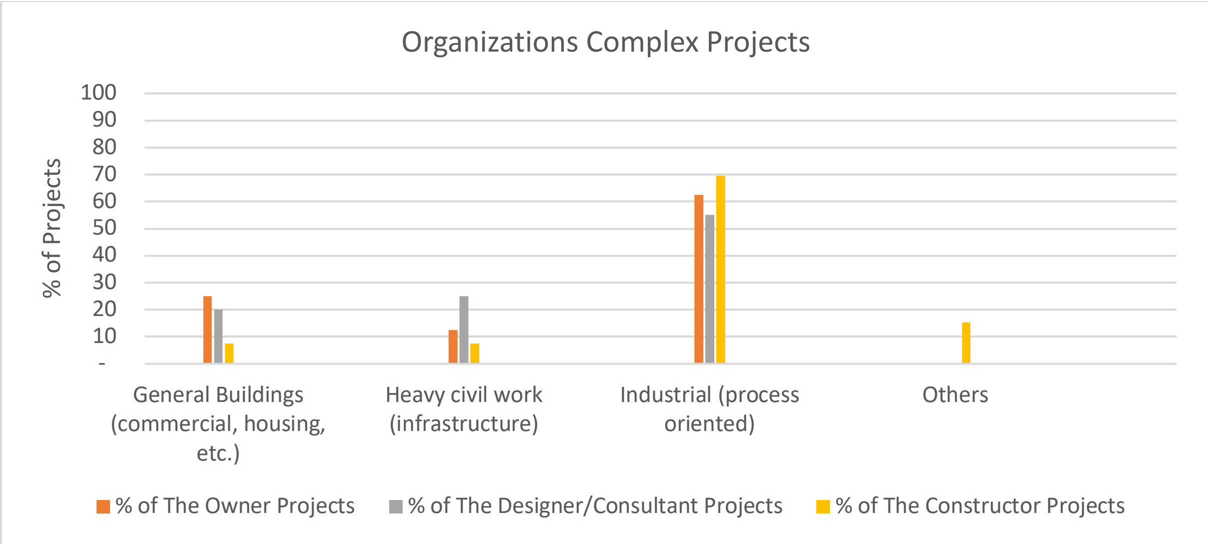

Figure 31: Organizations Complex Projects

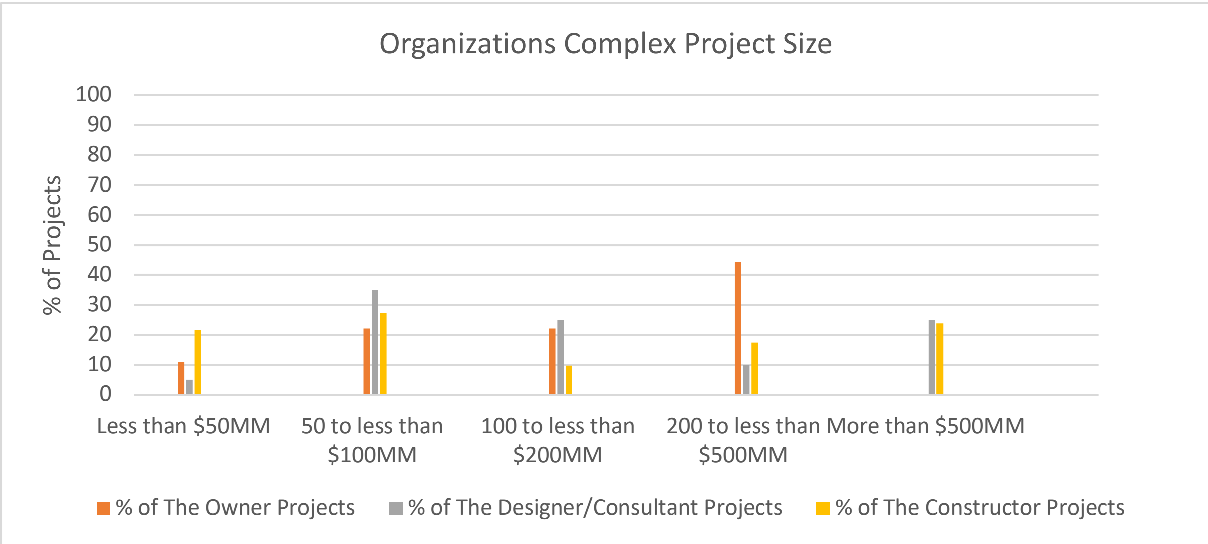

Figure 32: Organizations Complex Project Size

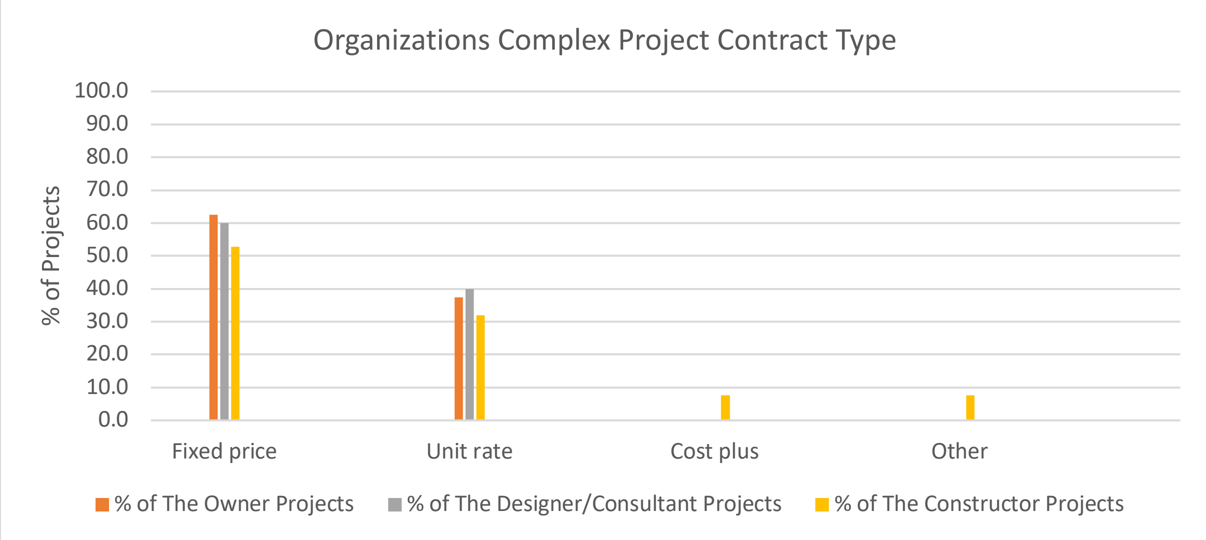

Figure 33: Organizations Complex Project Contract Type

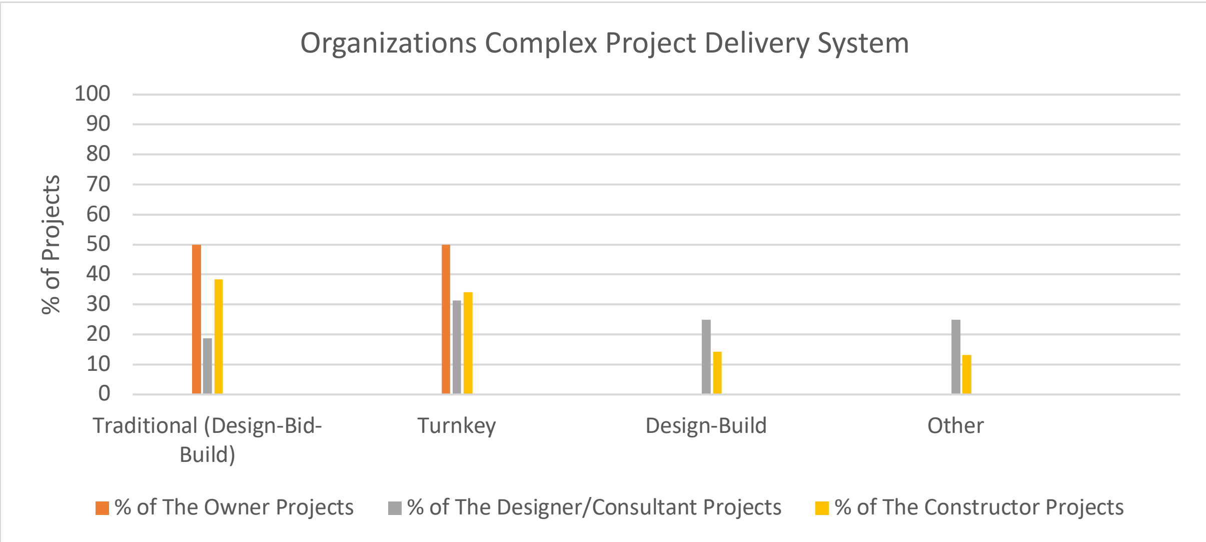

Figure 34: Organizations Complex Project Delivery System

The participants from owner, designer/consultant and constructor firms have different level of frequency in terms of including a specific section in the design bid documents for complex construction projects addressing the constructability issues. The majority of the participants (36%) claimed that they always addressing constructability issues in their design bid documents. However, only (3%) of the participants indicated that they never addressed the constructability issues in their design bid documents. Figure 35 and Figure 36 summarizes the level of frequency in terms of including a specific section in the design bid documents for complex construction projects addressing the constructability issues.

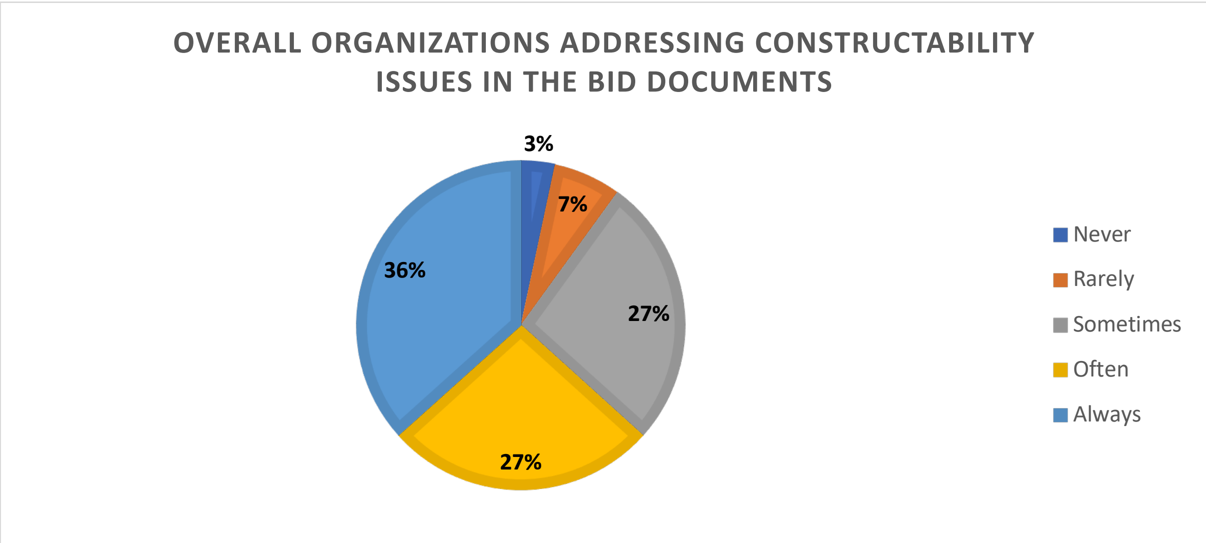

Figure 35: Overall Organizations Addressing Constructability Issues in the Bid Documents

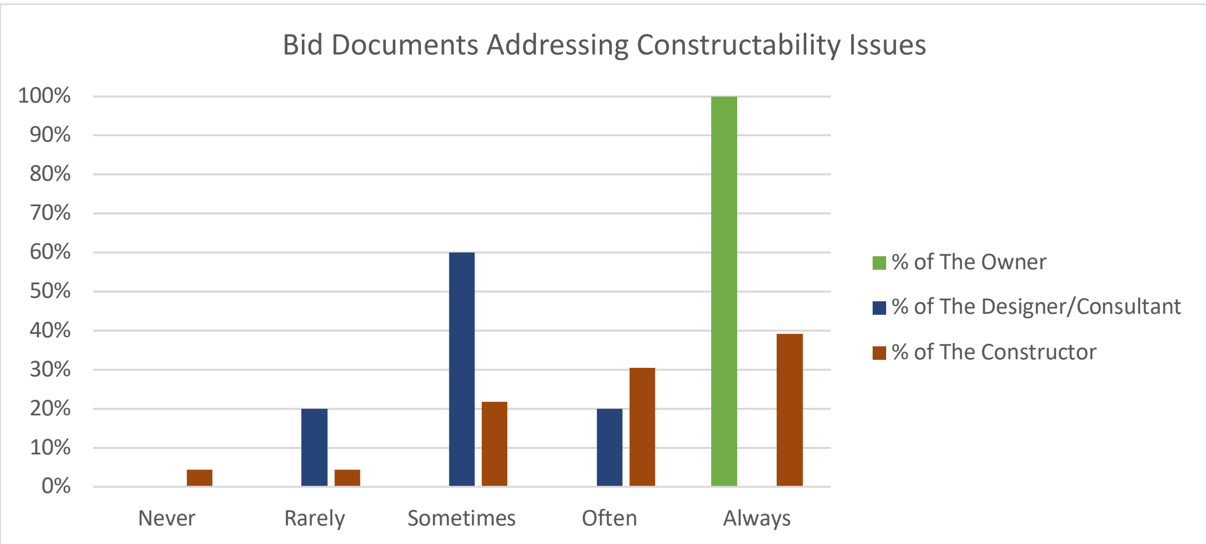

Figure 36: Bid Documents Addressing Constructability Issues

With the above-mentioned data collected from questions seeking information on the characteristics of the participants organizations acquired from questions in Section_2 of the questionnaire, it has been concluded that the participants organizations can be considered as qualified and trustworthy source of information.

4.2.2.3 part_3: constructability implementation for complex projects in Saudi construction industry

The participants from the owner, designer/consultant and constructor firms were asked whether they have a corporate constructability program or not in their organization. The results indicated that both of the participated owner firms are implementing the constructability program at the corporate level. Furthermore, most of the participated design/consultant firms (60%) are implementing the constructability program at the corporate level and the remaining (40%) indicated that they don't have a corporate constructability program. Moreover, most of the participated constructor firms (57%) are implementing the constructability program at the corporate level and (17%) indicated that they don't have a corporate constructability program. It is worth mentioning that the results indicated that (26%) of the constructor's participants do not know if their organizations have a corporate constructability program or not. Figure 37 and Figure 38 summarizes the availability of the corporate constructability program among the participated organizations.

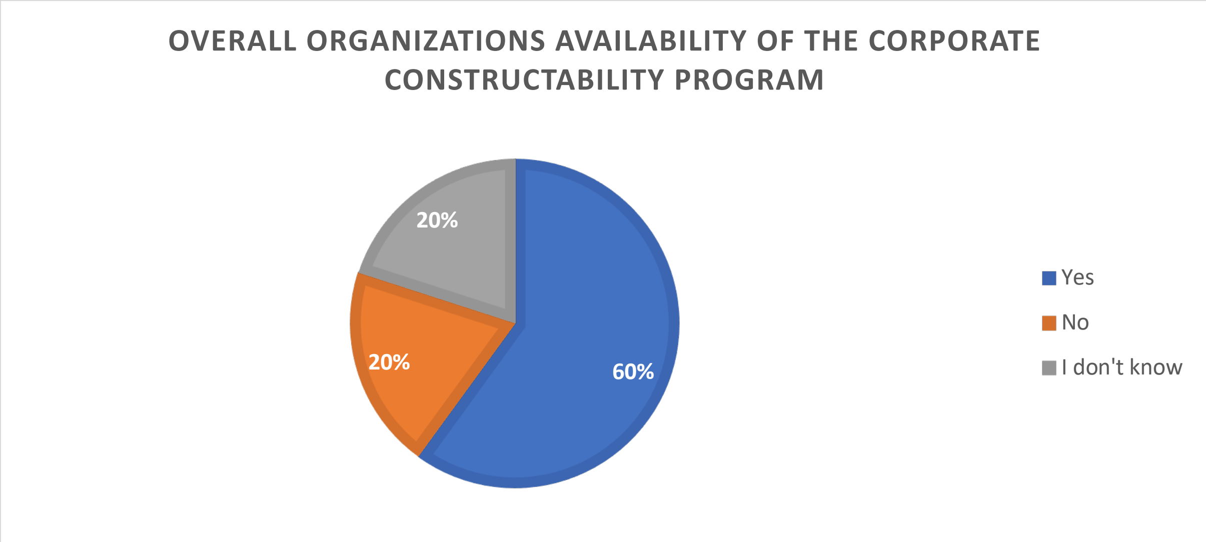

Figure 37: Overall organizations Availability of The Corporate Constructability Program

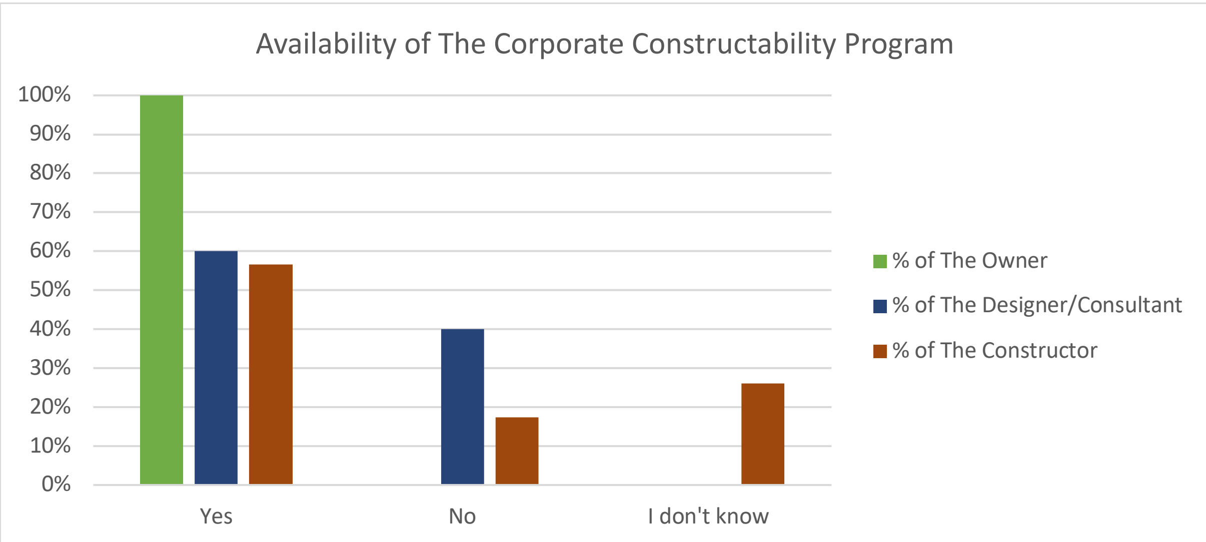

Figure 38: Availability of The Corporate Constructability Program

The participants from the owner, designer/consultant and constructor firms have indicated various of techniques utilized for implementing constructability concepts in their complex industrial construction projects. Most the participants have selected more than one technique utilized for implementing constructability concepts. The results indicated that both of the participated owner firms are utilizing a corporate constructability log/file as a technique for implementing the constructability concepts in their complex industrial construction projects. Furthermore, most of the participated design/consultant firms (80%) indicated that they have a formal implementation process, followed by (60%) indicated that brainstorming technique is utilized for implementing the constructability concepts in their complex industrial construction projects. Moreover, most of the participated constructor firms (95%) indicated that design review checklist technique, followed by (68%) indicated that brainstorming technique is utilized for implementing the constructability concepts in their complex industrial construction projects and (63%) indicated that they have a formal implementation process for implementing constructability concept. Figure 39 and Figure 40 summarizes the constructability techniques utilized by the participated organizations.

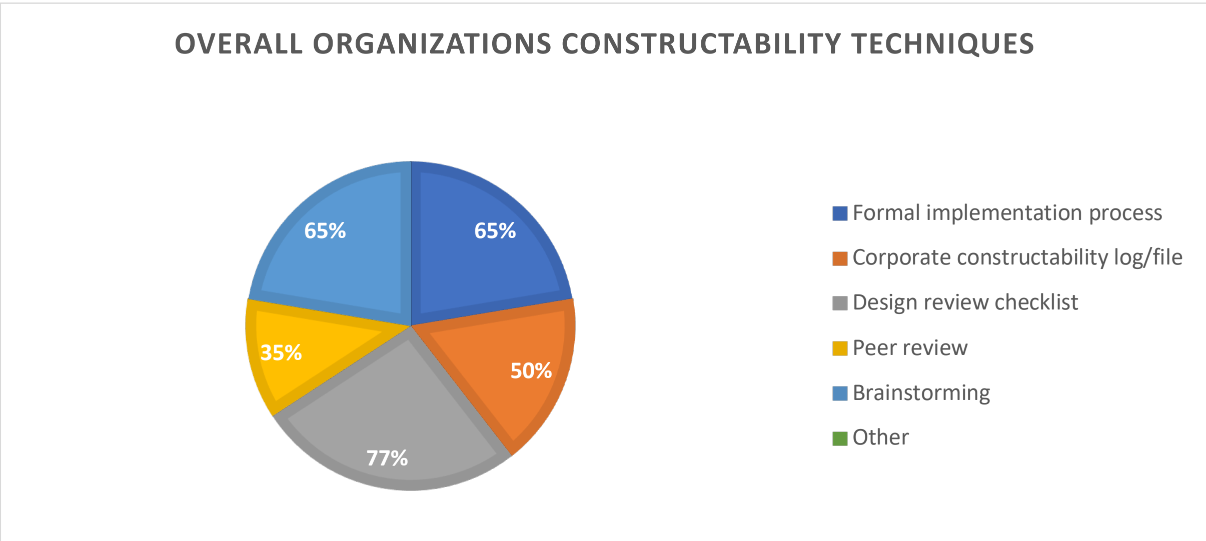

Figure 39: Overall organizations Constructability Techniques

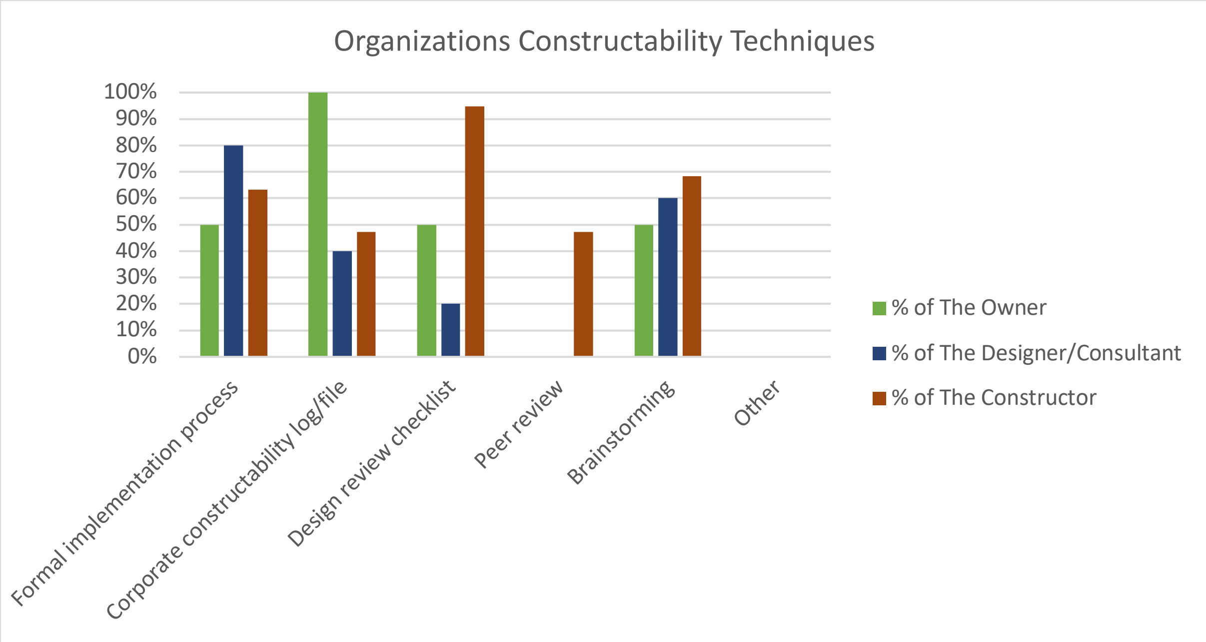

Figure 40: Organizations Constructability Techniques

The participants from the owner, designer/consultant and constructor firms were asked to identify the best individual for facilitating the implementation of the constructability review for complex industrial construction projects. Most of the participants (63%) have selected the third-party constructability consultant as the best choice for facilitating the constructability implementation, followed by designer in-house constructability consultant (53%) and owner in-house constructability consultant (43%). Figure 41 and Figure 42 shows the best option for facilitating the implementation of the constructability review for complex industrial construction projects.

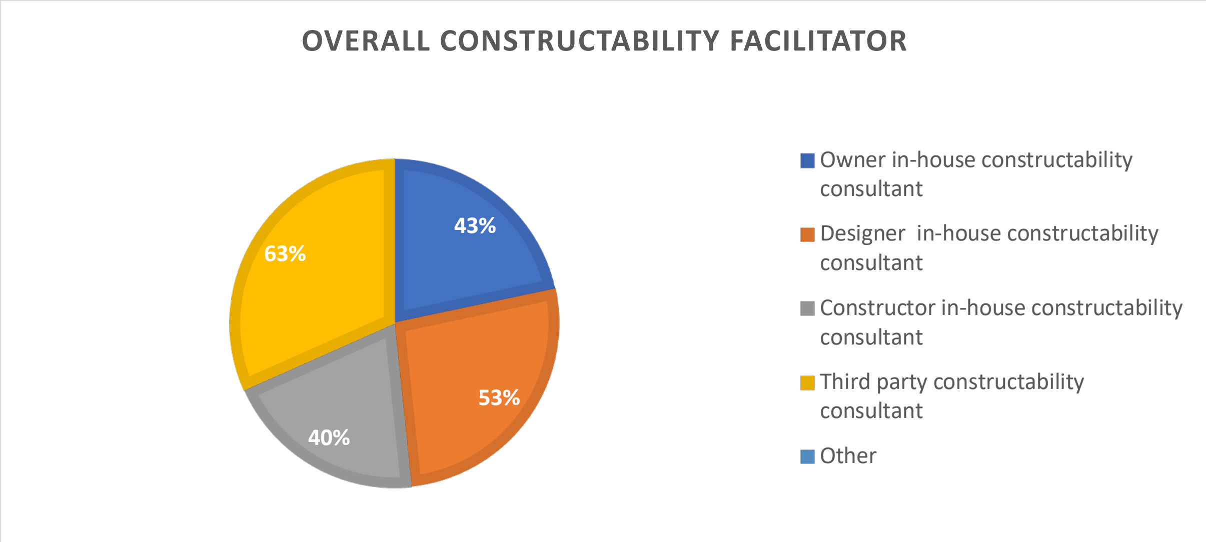

Figure 41:Overall Constructability Facilitator

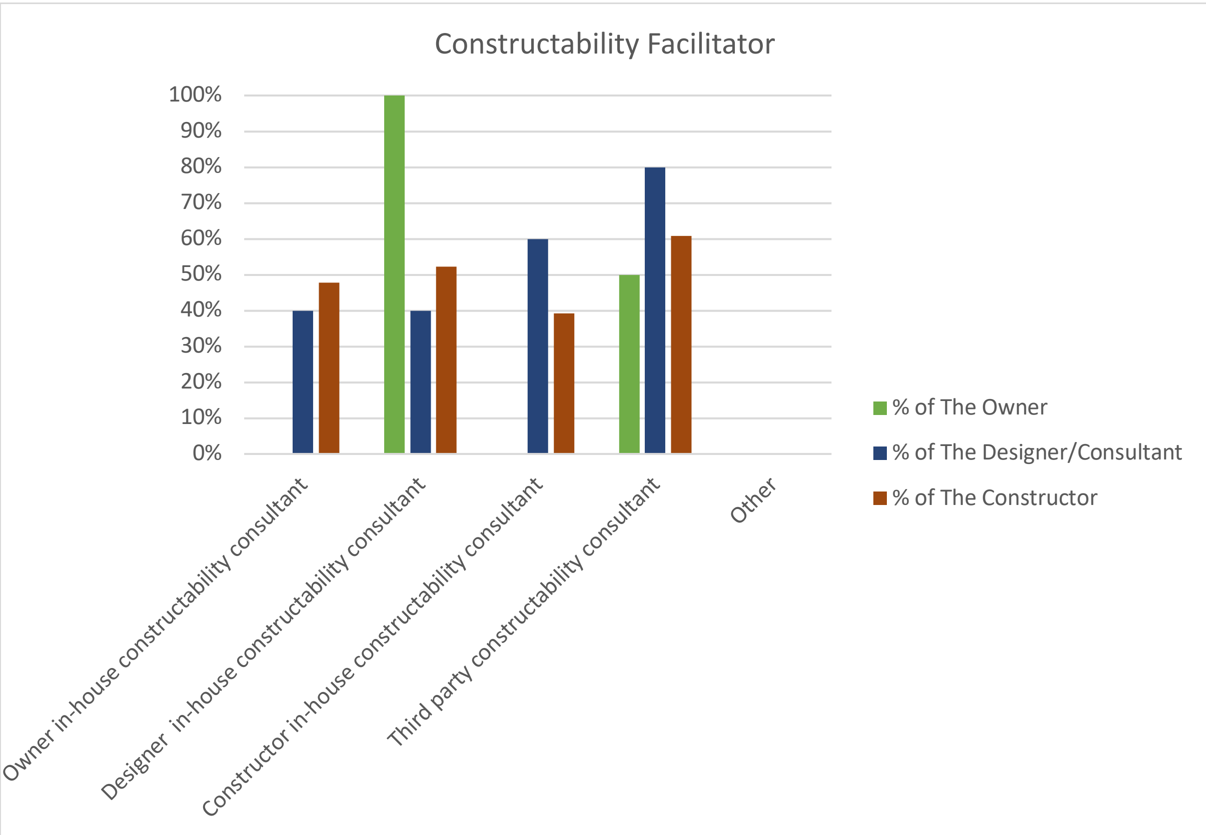

Figure 42: Constructability Facilitator

The participants from the owner, designer/consultant and constructor firms were asked to rate a set of key personnel with respect to the importance of their involvement in conducting constructability review for complex industrial construction projects. The questionnaire utilized five-points rate scale key personnel evaluation in order to allow respondent answering naturally. Each key personnel have a weight varies from one (1) to Five (5) as following:

- Not at all important = 1 point
- Slightly important = 2 points
- Moderately important = 3 points
- Very important = 4 points
- Extremely important = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between a set key personnel for their involvement in implementing constructability from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test is tabulated in Table 4.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	10.230303	10	1.0230303	1.29434162	0.23242191	1.86043772
Within Groups	252.133333	319	0.79038662			
Total	262.363636	329				

Table 4: Data Variance of Constructability Implementation Key Personnel

Since P-value is greater than 0.05 and (F) is less than (F crit), then we do not reject the Null Hypothesis (H_0) which indicates that the means of the populations are equal. Answers were analyzed to provide the results as mean and standard deviation for each key personnel with respect to the importance of their involvement in conducting constructability review for complex industrial construction projects. Table 5 and Table 6 shows the responses mean, standard deviation and the ranking of each key personnel from the designer/consultant and constructor firms' perspectives respectively.

Key Personnel	Mean	Standard Deviation	Rank
Lead project engineer (owner)	4.80	0.45	1
Construction manager (constructor)	4.80	0.45	
Constructability consultant/ facilitator	4.80	0.45	
Project engineer (owner)	4.60	0.55	2
Lead project engineer (designer)	4.60	0.55	
Discipline engineer (designer)	4.60	0.55	
End user representative	4.40	0.89	3
Site superintendent (constructor)	4.40	0.89	
Site project engineer (constructor)	4.40	0.89	
Discipline manager (designer)	4.20	1.30	4
Project manager (owner)	4.00	1.22	5

Table 5: Constructability Implementation Key Personnel (Designers/Consultants perspective)

Key Personnel	Mean	Standard Deviation	Rank
Construction manager (constructor)	4.57	0.79	1
Constructability consultant/ facilitator	4.52	0.95	2
Site project engineer (constructor)	4.39	0.89	3
Lead project engineer (owner)	4.35	0.83	4
Project engineer (owner)	4.35	0.98	
End user representative	4.30	0.88	5
Project manager (owner)	4.22	0.85	6
Site superintendent (constructor)	4.22	0.95	
Lead project engineer (designer)	4.17	0.94	7
Discipline engineer (designer)	4.17	1.03	
Discipline manager (designer)	3.87	1.14	8

Table 6: Constructability Implementation Key Personnel (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to indicate how the involvement of the construction key personnel during the early stages of the project design is important to enhance better constructible project and the results shows that (80%) of the participants agrees on this statemen. Figure 43 and Figure 44 summarizes the participants opinion on the importance of the construction key personnel involvement during the early stages of the project design.

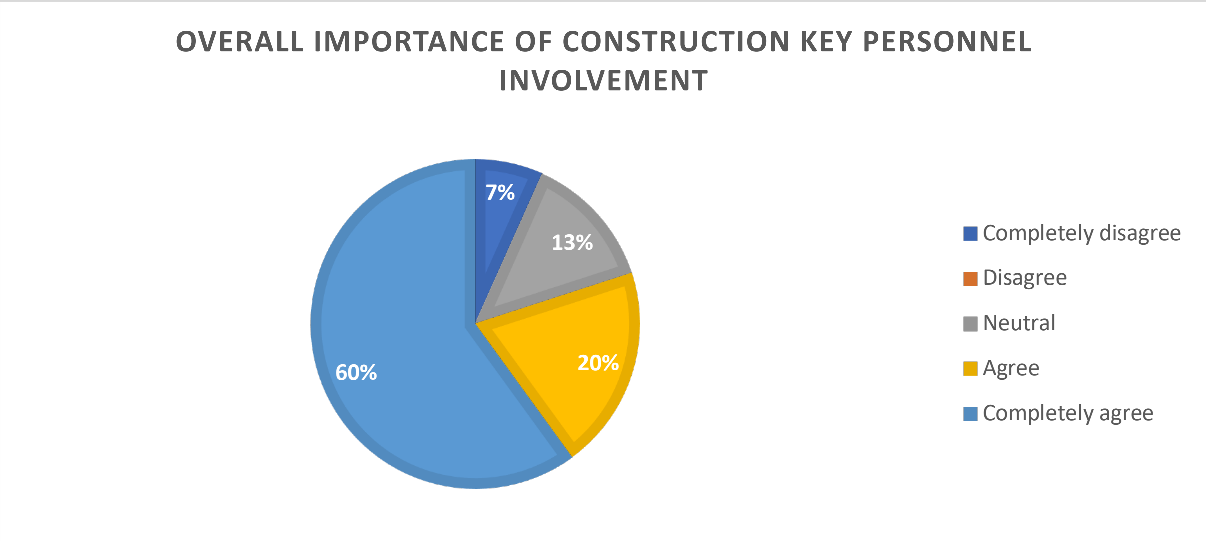

Figure 43:Overall Importance of Construction Key Personnel Involvement

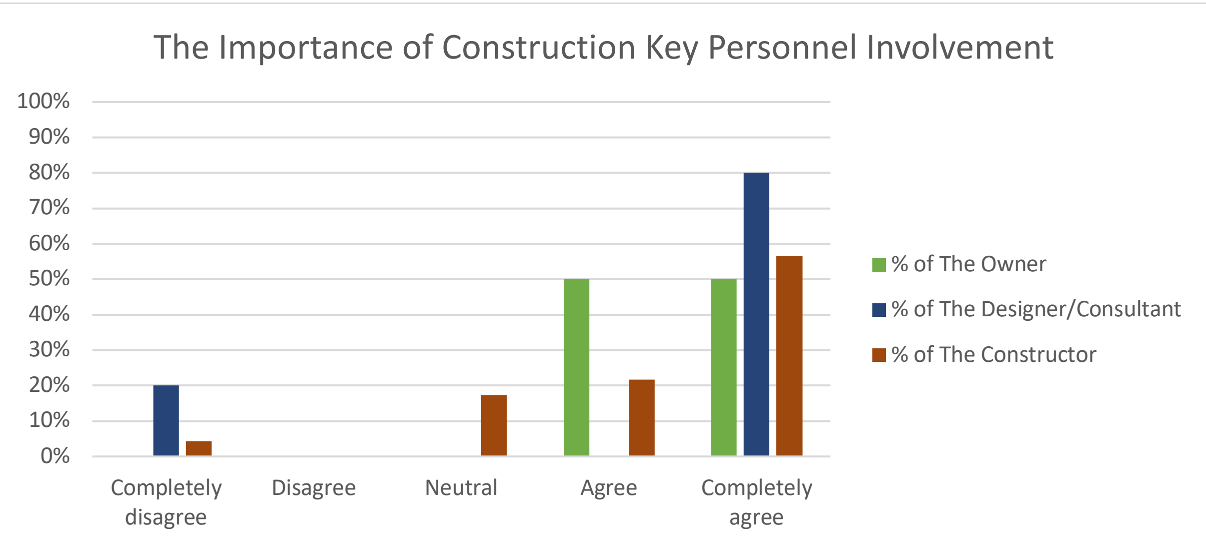

Figure 44: The Importance of Construction Key Personnel Involvement

To demonstrate the utilization level of the constructability concepts developed by the Construction Industry Institute (CII), the participants from the owner, designer/consultant and constructor firms were asked to identify the constructability concepts usually covered during the implementation of the constructability review in their complex industrial construction projects. it's been found that the majority of the constructability concepts are usually covered during the implementation of the constructability review in the complex industrial construction projects from the owners prospective. However, some constructability concepts (such as; permanent and temporary site layouts promote efficient construction, design elements are standardized, and designs facilitate construction and field productivity under adverse weather condition) have not been given a sufficient attention from the owners prospective. Furthermore, it's been found that the most constructability concept usually utilized by the designer/consultant firms during the implementation of the constructability review in their complex industrial construction projects is that the design and procurement schedules are construction-sensitive. On the other hand, development of the project contracting strategy involves construction knowledge and experience, advanced information technologies are applied to facilitate efficient construction, and design elements are standardized are the least constructability concepts utilized among the designer/consultant firms. Moreover, it's been found that the most constructability concept usually utilized by the constructor firms during the implementation of the constructability review in their complex industrial construction projects are constructability implementation plans are an integral part of the project execution plan, and procurement, construction and startup efficiency are considered in the development of contract documents. On the other hand, advanced information technologies are applied to facilitate efficient construction, and designs are configured to enable efficient construction and use of efficient technologies are the least constructability concepts utilized among the constructor firms. Figure 45 and Figure

46 summarizes the constructability concepts utilization level among the owner, designer/consultant and constructor firms.

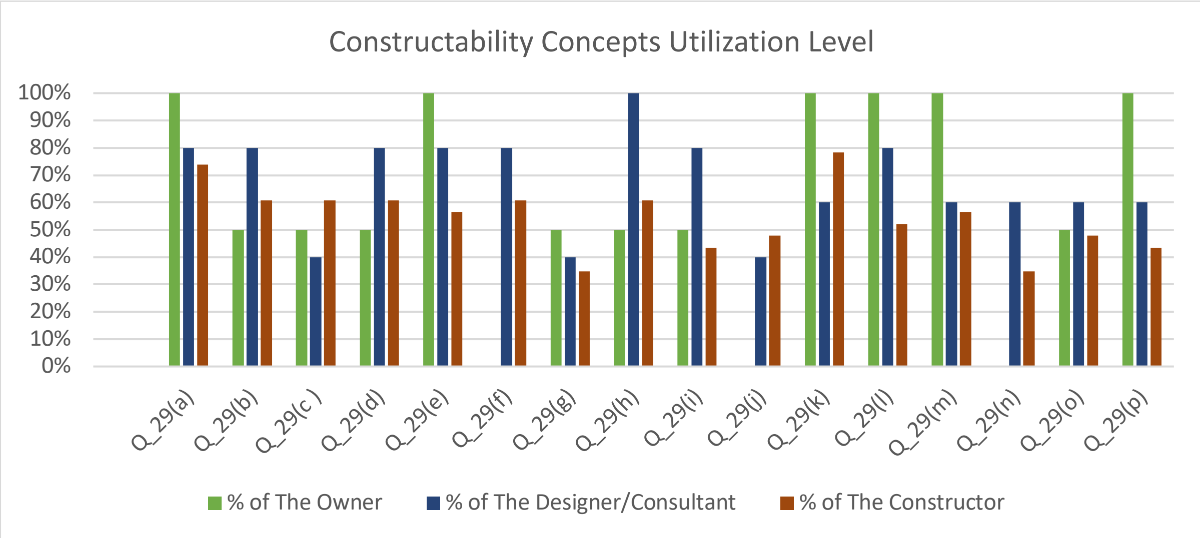

Figure 45: Constructability Concepts Utilization Level

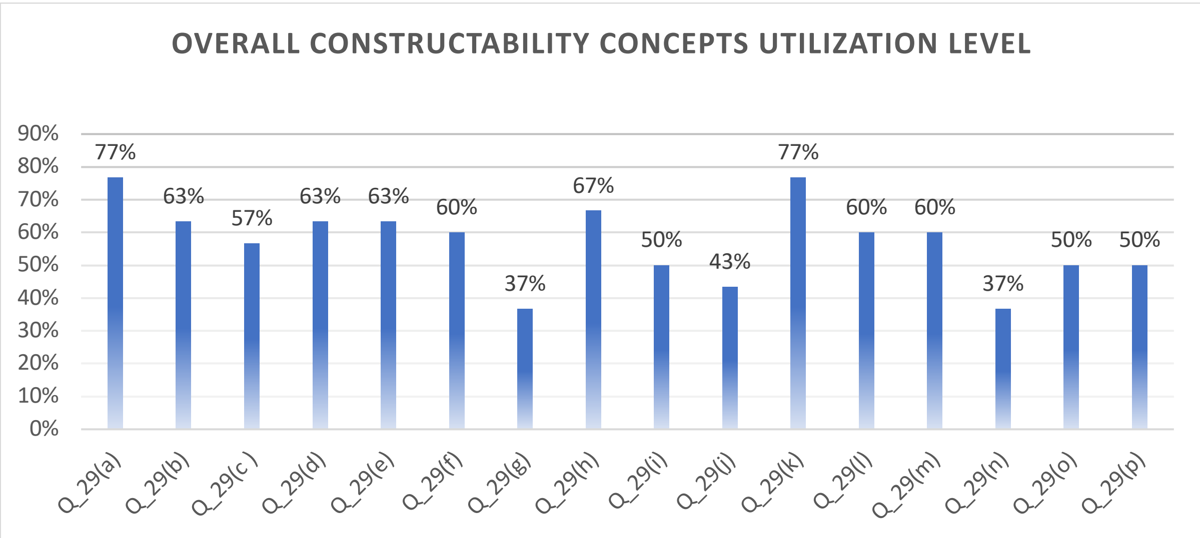

Figure 46: Overall Constructability Concepts Utilization Level

Where,

Q_29(a): Constructability implementation plans are an integral part of the Project Execution Plan
Q_29(b): Early project feasibility planning takes advantage of construction knowledge and experience

Q_29(c): Development of the project contracting strategy involves construction knowledge and experience
Q_29(d): Project schedules are construction - and startup-sensitive
Q_29(e): Important, early design decisions consider modularization/preassembly, construction automation, and other major construction method options
Q_29(f): Permanent and temporary site layouts promote efficient construction
Q_29(g): Advanced information technologies are applied to facilitate efficient construction
Q_29(h): Design and procurement schedules are construction-sensitive
Q_29(i): Designs are configured to enable efficient construction and use of efficient technologies
Q_29(j): Design elements are standardized
Q_29(k): Procurement, construction and startup efficiency are considered in the development of contract documents
Q_29(l): Module/preassembly designs facilitate fabrication, transport, and field installation
Q_29(m): Designs promote construction accessibility of personnel, material, and equipment
Q_29(n): Designs facilitate construction and field productivity under adverse weather conditions
Q_29(o): Project plans enhance security during construction
Q_29(p): Innovative construction management and field methods are applied to increase construction efficiency

The participants from the owner, designer/consultant and constructor firms were asked to rate a set of benefits as a result of implementing the constructability practices in complex industrial construction projects. The questionnaire utilized five-points rate scale constructability benefits evaluation in order to allow respondent answering naturally. Each benefit has a weight varies from one (1) to Five (5) as following:

- Completely disagree = 1 point
- Disagree = 2 points
- Neutral = 3 points
- Agree = 4 points
- Completely Agree = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between a set of constructability benefits from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test for designer/consultant and constructor firms is tabulated in Table 7.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.3333333	15	1.22222222	1.41659728	0.13473814	1.68797897
Within Groups	400.333333	464	0.86278736			
Total	418.666667	479				

Table 7: Data Variance of Constructability Implementation Benefits

Since P-value is greater than 0.05 and (F) is less than (F crit), then we do not reject the Null Hypothesis (H_0) which indicates that the means of the populations are equal. Answers were analyzed to provide the results as mean and standard deviation for each benefit as a result of implementing the constructability practices in complex industrial construction projects. Table 8 and Table 9 shows the responses mean, standard deviation and the ranking of each constructability benefit from the designer/consultant and constructor firms' perspectives respectively.

Constructability Implementation Benefit	**Mean**	**Standard Deviation**	**Rank**
Reduce amount of rework	4.60	0.55	1
Improve the communication	4.60	0.55	
Improve project quality	4.60	0.55	
Reduce schedule duration	4.40	0.55	2
Increase problem avoidance	4.40	0.55	
Increase commitment of the project team	4.40	0.89	
Improve project safety	4.40	0.89	
Enhance team building and cooperation	4.40	0.89	
Reduce construction cost (labor, material and equipment)	4.20	0.84	3
Increase construction flexibility	4.20	0.45	
Reduce disruption to current production	4.00	0.71	4
Reduce maintenance cost	4.00	1.22	
Improve site accessibility	4.00	1.22	
Smoothen the start-up	3.80	1.30	5
Increase of understanding of purpose/ effective of individual's involvement	3.80	1.30	
Reduce engineering cost	3.20	1.30	6

Table 8: Constructability Implementation Benefits (Designers/Consultants perspective)

Constructability Implementation Benefit	Mean	Standard Deviation	Rank
Reduce amount of rework	4.30	0.88	1
Improve project safety	4.22	0.80	2
Improve site accessibility	4.22	0.80	
Reduce construction cost (labor, material and equipment)	4.13	1.01	3
Reduce schedule duration	4.13	1.18	
Reduce disruption to current production	4.13	0.81	
Improve project quality	4.13	0.69	
Increase construction flexibility	4.09	0.79	4
Enhance team building and cooperation	4.09	0.85	
Increase problem avoidance	4.04	1.02	5
Smoothen the start-up	4.00	1.04	6
Increase of understanding of purpose/ effective of individual's involvement	3.96	0.82	7
Increase commitment of the project team	3.87	1.06	8
Improve the communication	3.87	0.92	
Reduce maintenance cost	3.83	1.15	9
Reduce engineering cost	3.52	1.27	10

Table 9: Constructability Implementation Benefits (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to indicate the average percentage of schedule reduction and cost saving that they can anticipate by implementing the constructability practices for complex industrial construction projects. Both participants form the owner firms indicated that implementing constructability concepts in their complex industrial construction projects helped them to have schedule reduction by more than 7% of the original project completion schedule. Furthermore, most of the designer's/consultant's participants (60%) also indicated that implementing constructability concepts in their complex industrial construction projects helped them to have schedule reduction by more than 7% of the original project completion schedule and the remaining (40%) believes that implementing constructability has contributed only by (3%- 5%) schedule reduction of the total project duration. Moreover, (30%) of the constructor's participants indicated that implementing constructability concepts in their complex industrial construction projects helped them to have schedule reduction by (3% - 5%) of the total project duration and another (30%) of the constructor's participants believes that it can reduce more than 7%. The participants opinion on the constructability implementation contribution on the schedule reduction of the total project duration is summarized in Figure 47 and Figure 48.

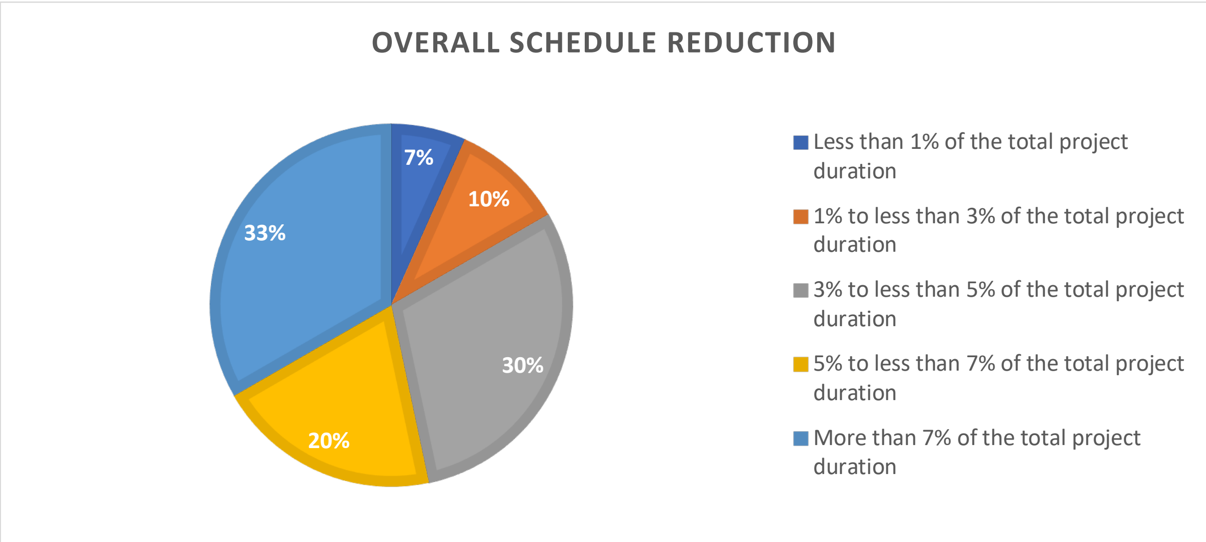

Figure 47: Overall Schedule Reduction

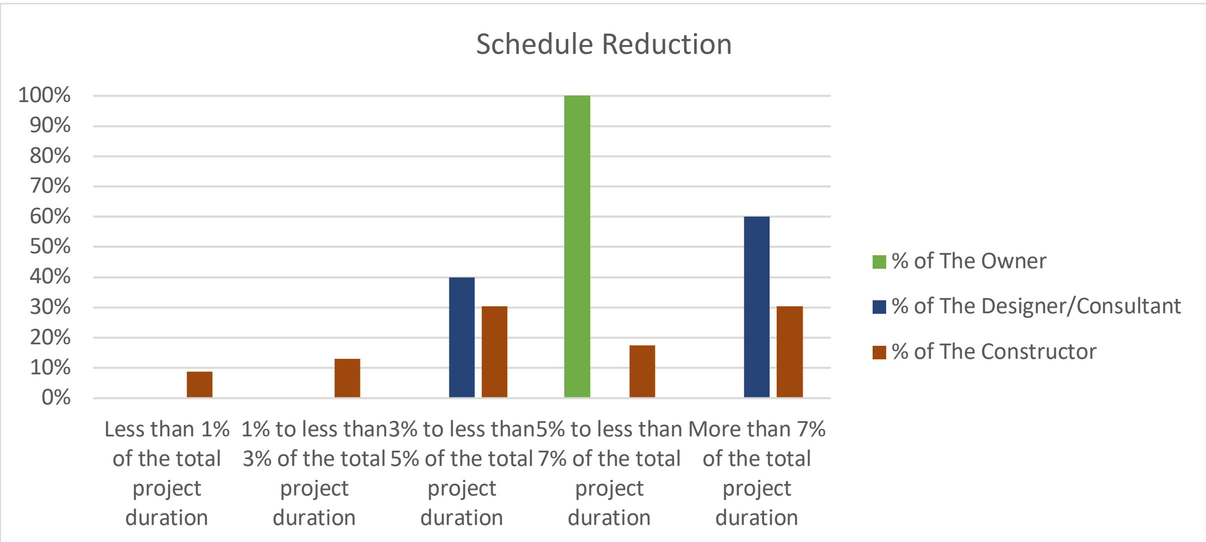

Figure 48: Schedule Reduction

On the other hand, both participants form the owner firms and most of the constructor's participants (30%) indicated that implementing constructability concepts in their complex industrial construction projects helped them to have cost saving by (1% - 3%) of the total project budget. Furthermore, most of the designer's/consultant's participants (40%) indicated that implementing constructability concepts can contributes in (1% - 3%) as well as (3% - 5%) cost saving of the total project budget and the remaining (20%) indicated that implementing constructability concepts in their complex industrial construction projects helped them to have cost saving by more than 5% of the total project budget. The participants opinion on the constructability implementation contribution on the cost saving of the total project budget is summarized in Figure 49 and Figure 50.

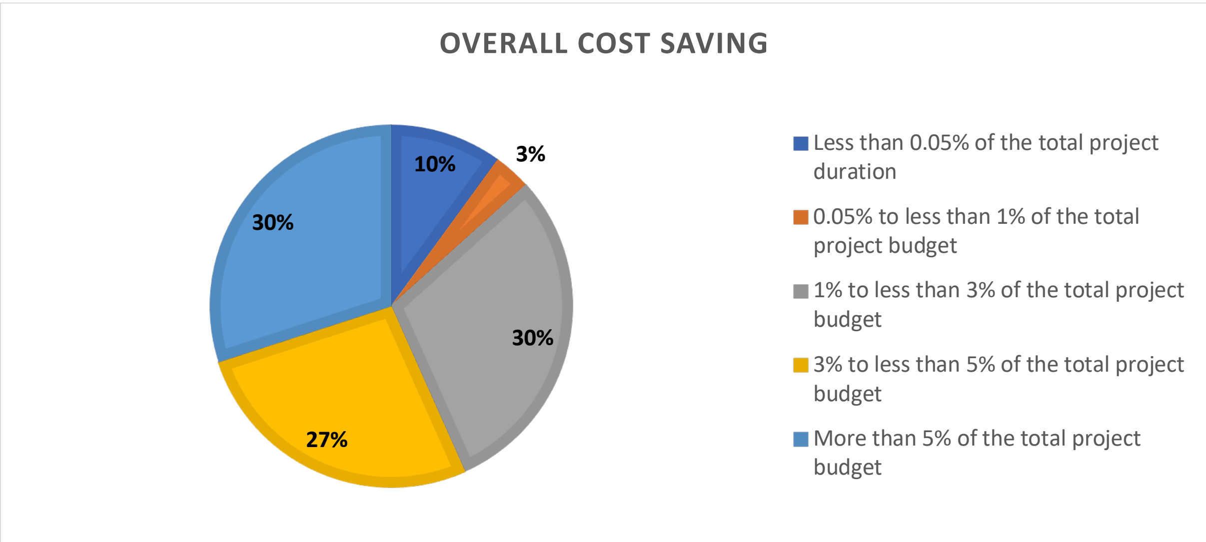

Figure 49: Overall Cost Saving

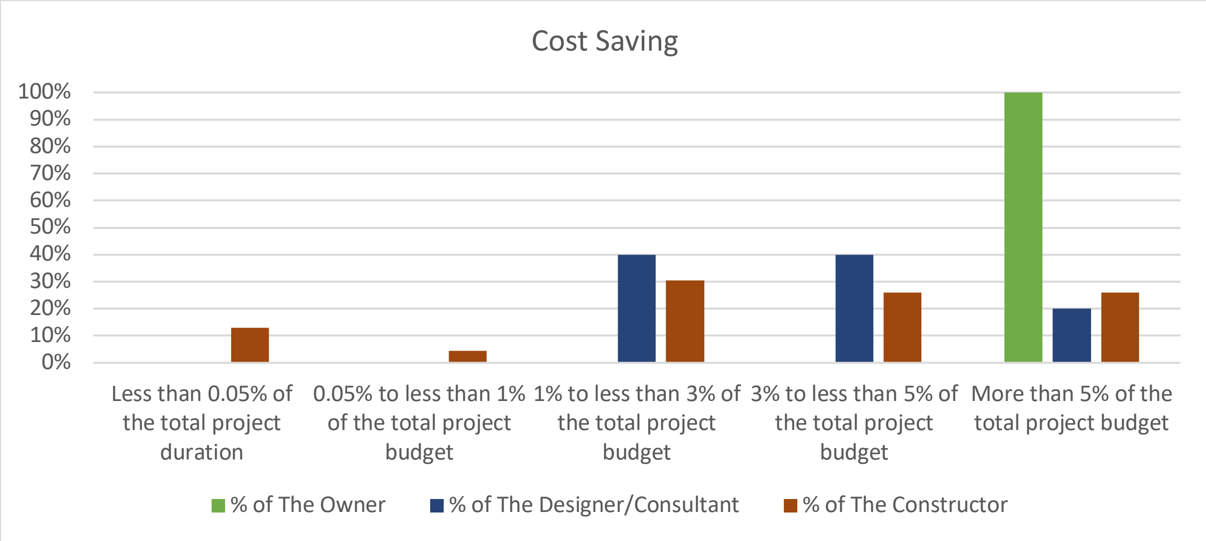

Figure 50: Cost Saving

It's worth mentioning that the majority of the participants from the owner, designer/consultant and constructor firms indicated that the fee for conducting the constructability review is ranging from $15,000 to less than $20,000 for each complex industrial construction project. The participants opinion on the constructability implementation fee is summarized in Figure 51 and Figure 52.

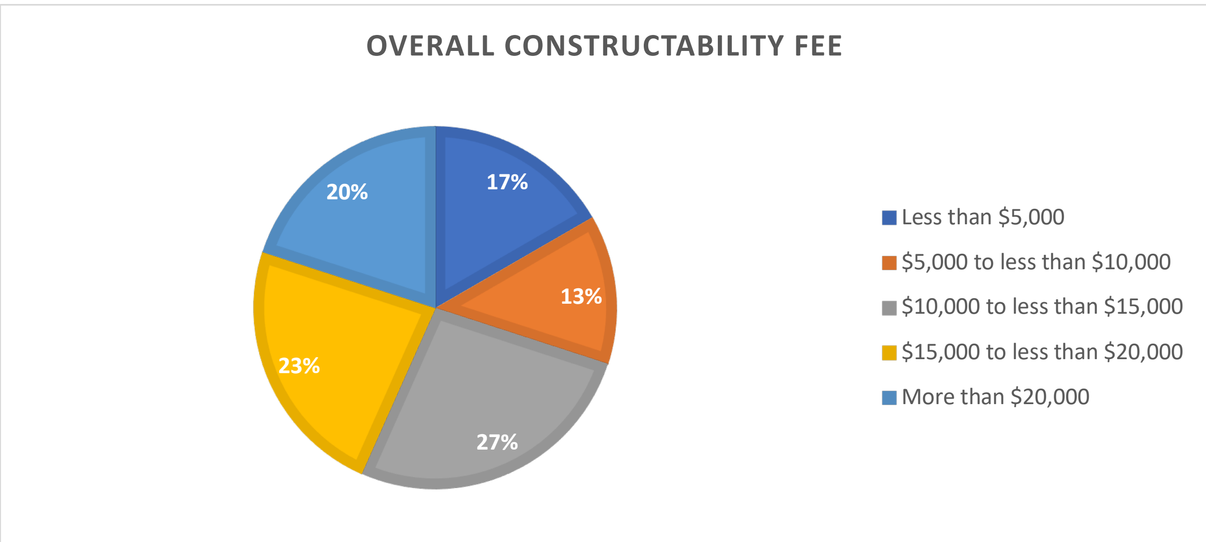

Figure 51: Overall Constructability Fee

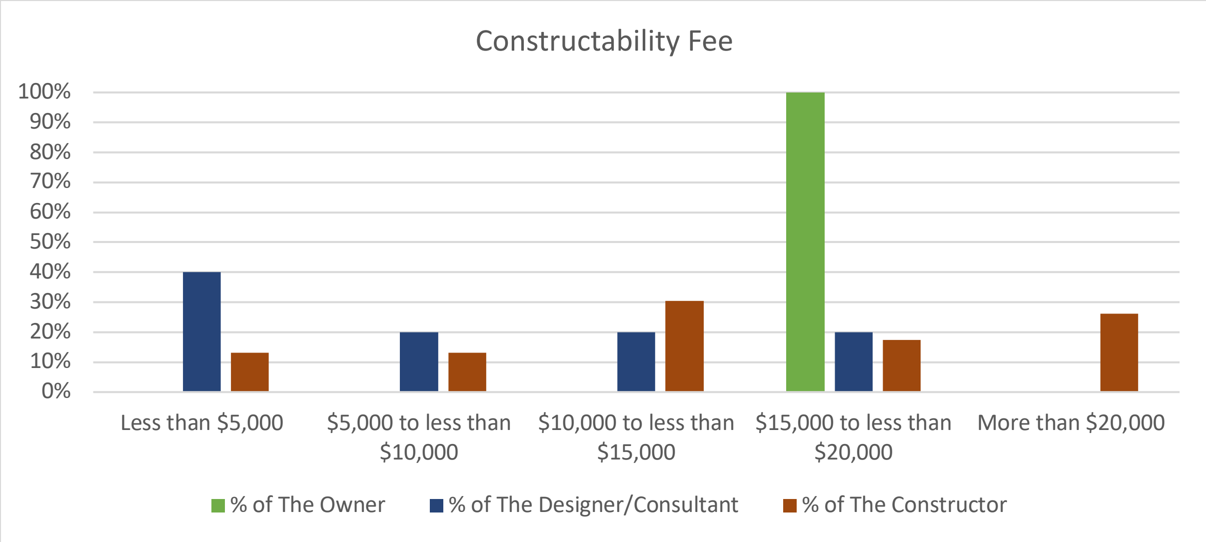

Figure 52: Constructability Fee

The participants from the owner, designer/consultant and constructor firms were asked to rate a set of barriers with respect to their effect on the implementation of constructability practices in complex industrial construction projects. The questionnaire utilized five-points rate scale constructability barriers evaluation in order to allow respondent answering naturally. Each barrier has a weight varies from one (1) to Five (5) as following:

- Absolutely insignificant = 1 point
- Slightly insignificant = 2 points
- Neutral = 3 points
- Slightly significant = 4 points
- Absolutely significant = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between a set of constructability barriers from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test's result is tabulated in Table 10.

Where,

(SS): Sum of Squares

(df): Degree of Freedom

(MS): Means Square

(F): F Ratio

(F crit): F Critical

(α): Significance Level = 5% (0.05)

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	13.41333333	14	0.958095238	0.713690442	0.761142356	1.714558206
Within Groups	583.9666667	435	1.342452107			
Total	597.38	449				

Table 10: Data Variance of Constructability Implementation Barriers

Since P-value is greater than 0.05 and (F) is less than (F crit), then we do not reject the Null Hypothesis (H_0) which indicates that the means of the populations are equal. Answers were analyzed to provide the results as mean and standard deviation for each barrier with respect to its effect on the implementation of constructability practices in complex industrial construction projects. Table 11 and Table 12 shows the responses mean, standard deviation and the ranking of each constructability barriers from the designer/consultant and constructor firms' perspectives respectively.

Constructability Implementation Barrier	Mean	Standard Deviation	Rank
Lack of team-building or partnering (client - contractor relationship)	4.60	0.55	1
The “right people” were/are not available	4.20	0.84	2
The owner misdirected the design objectives and designer performance measures	4.20	0.84	
The owner's reluctance to invest additional money, effort, and time in early	4.00	1.73	3
Contractor or construction input is requested too late to be of value	4.00	0.71	
Poor timeliness of input for the constructor	4.00	1.00	
Complacency with the status quo	3.60	0.55	4
The owner were/are lack of awareness/understanding of the concepts of constructability; no procedural “roadmap” is available	3.40	1.52	5
Owner perception that “we do it”	3.40	1.52	
Use of lump-sum competitive contracting	3.40	1.14	
Designer perception that “we do it”	3.40	1.52	
The designer were/are lack of construction experience/qualified personnel	3.40	0.89	
The designer were/are lack of awareness/understanding of constructability concepts	3.20	1.30	6
Lack of mutual respect between designers and constructors	3.00	0.71	7
The constructor had/ has poor communication skills; design criticism is often non-constructive or communicated in an offensive, tactless manner	3.00	1.58	

Table 11: Constructability Implementation Barriers (Designers/Consultants perspective)

Constructability Implementation Barrier	Mean	Standard Deviation	Rank
The “right people” were/are not available	3.87	1.32	1
The designer were/are lack of awareness/understanding of constructability concepts	3.74	1.25	2
The designer were/are lack of construction experience/qualified personnel	3.74	1.25	
Owner perception that “we do it”	3.65	0.93	3
The constructor had/ has poor communication skills; design criticism is often non-constructive or communicated in an offensive, tactless manner	3.61	0.99	4
Lack of team-building or partnering (client - contractor relationship)	3.57	1.38	5
The owner's reluctance to invest additional money, effort, and time in early	3.57	1.20	
Designer perception that “we do it”;	3.57	1.12	
Poor timeliness of input for the constructor	3.57	1.16	
The owner were/are lack of awareness/understanding of the concepts of constructability; no procedural “roadmap” is available	3.48	1.31	6
Lack of mutual respect between designers and constructors	3.43	1.16	7
Complacency with the status quo	3.35	0.88	8
Use of lump-sum competitive contracting	3.22	1.20	9
Contractor or construction input is requested too late to be of value	3.22	1.00	
The owner misdirected the design objectives and designer performance measures	3.17	1.19	10

Table 12: Constructability Implementation Barriers (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to rate a set of success factors for implementing the constructability practices for complex industrial construction projects. The questionnaire utilized five-points rate scale each success factor evaluation in order to allow respondent answering naturally. Each success factor has a weight varies from one (1) to Five (5) as following:

- Not at all important = 1 point
- Slightly important = 2 points
- Moderately important = 3 points
- Very important = 4 points
- Extremely important = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between a set of constructability success factors from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test is tabulated in Table 13.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	22.2	19	1.16842105	1.36318401	0.13854063	1.60449572
Within Groups	497.133333	580	0.85712644			
Total	519.333333	599				

Table 13: Data Variance of Constructability Implementation Success Factors

Since P-value is greater than 0.05 and (F) is less than (F crit), then we do not reject the Null Hypothesis (H_0) which indicates that the means of the populations are equal. Answers were analyzed to provide the results as mean and standard deviation for each success factor for constructability implementation for complex industrial construction projects. Table 14 and Table 15 shows the responses mean, standard deviation and the ranking of each success factor from the designer/consultant and constructor firms' perspectives respectively.

Success Factors for Implementing Constructability	Mean	Standard Deviation	Rank
Ensuring the implementation of the constructability recommendations	4.80	0.45	1
Integrating the constructability as part of the project execution plan	4.60	0.55	2
Early involvement of construction expertise at the project design phase	4.60	0.55	
Studying the site layout (site access, fabrication yard, storage area and truck roads ... etc.)	4.60	0.55	
Understanding the project goals and objectives	4.40	0.55	3
Utilizing the lesson-learned database and best-practices for other projects	4.40	0.89	
Early development of the project schedule goals as construction driven	4.20	0.45	4
Reviewing the applicability of the modularization and preassemble concepts during the design phase	4.20	0.84	
Developing competent constructability team	4.00	0.71	5
Early involvement of construction expertise in the development of the contracting strategy	4.00	1.22	
Planning the sequence of the construction activities during the design phase	4.00	0.71	
Reviewing the resources allocation and its accessibility to the project's site at the design phase	4.00	0.71	
Developing the plan for start-up during the design phase	4.00	0.71	
Utilizing the construction innovation during the construction phase	4.00	1.22	
Early determining the primary construction methods	3.80	0.45	6
Reviewing the applicability of the new developed construction technologies	3.80	0.45	
Ensuring the design simplicity for the construction personnel	3.80	0.84	
Ensuring the standardization of the design elements	3.80	1.30	
Ensuring the simplicity of the technical specifications for materials and equipment	3.80	1.10	
Planning for preventive methods for unforeseen wither conditions	3.60	0.89	

Table 14: Constructability Implementation Success Factors (Designers/Consultants perspective)

Success Factors for Implementing Constructability	Mean	Standard Deviation	Rank
Utilizing the lesson-learned database and best-practices for other projects	4.39	0.89	1
Planning the sequence of the construction activities during the design phase	4.39	0.89	
Integrating the constructability as part of the project execution plan	4.35	0.88	2
Early involvement of construction expertise at the project design phase	4.35	0.88	
Ensuring the implementation of the constructability recommendations	4.30	0.93	3
Developing competent constructability team	4.22	0.85	4
Studying the site layout (site access, fabrication yard, storage area and truck roads ... etc.)	4.22	1.13	
Understanding the project goals and objectives	4.09	1.00	5
Early determining the primary construction methods	4.09	1.04	
Developing the plan for start-up during the design phase	4.09	0.85	
Ensuring the standardization of the design elements	4.04	0.88	6
Early involvement of construction expertise in the development of the contracting strategy	4.00	1.21	7
Early development of the project schedule goals as construction driven	4.00	1.09	
Reviewing the applicability of the new developed construction technologies	4.00	1.00	
Ensuring the simplicity of the technical specifications for materials and equipment	4.00	1.09	
Reviewing the applicability of the modularization and preassemble concepts during the design phase	4.00	0.95	
Ensuring the design simplicity for the construction personnel	3.96	0.98	8
Reviewing the resources allocation and its accessibility to the project's site at the design phase	3.96	0.93	
Utilizing the construction innovation during the construction phase	3.91	1.12	9
Planning for preventive methods for unforeseen wither conditions	3.83	0.98	10

Table 15: Constructability Implementation Success Factors (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to indicate how effectively the lessons learned being communicated across projects in their organizations and the results shows that (70%) of the participants are satisfied with how their organizations are handling the lessons learned practices. Figure 53 and Figure 54 summarizes the participants opinion on the lessons learned communication across projects in their organizations.

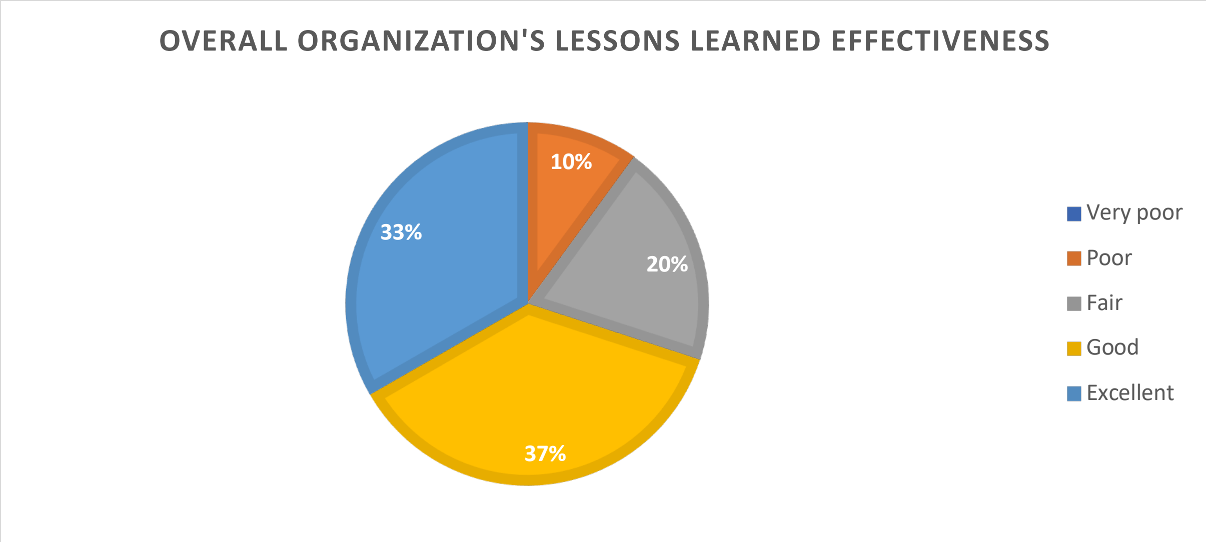

Figure 53: Overall Organization's Lessons Learned Effectiveness

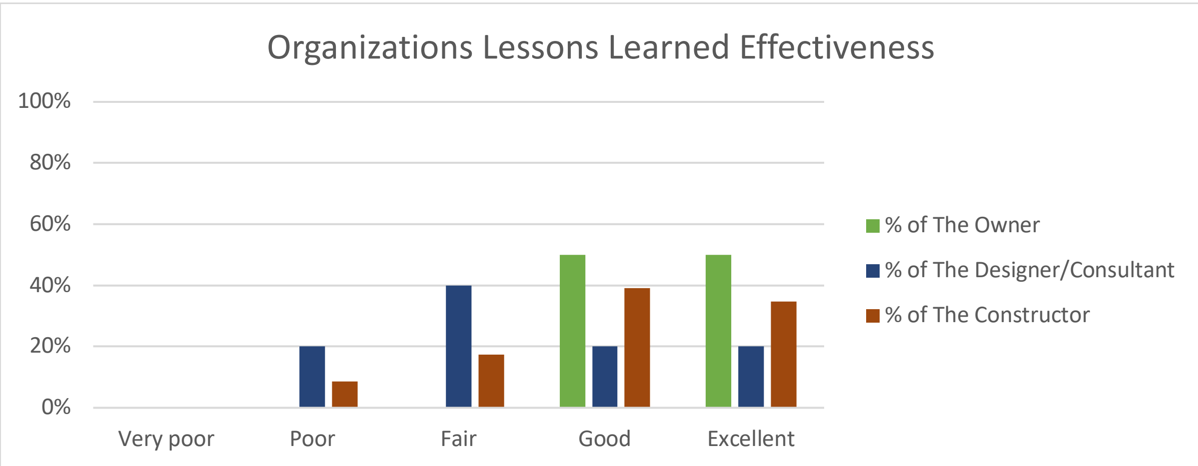

Figure 54: Organizations Lessons Learned Effectiveness

The participants from the owner, designer/consultant and constructor firms were asked to rate a set of project complexity factors with respect to their effects on the project complexity level for industrial construction projects. The questionnaire utilized five-points rate scale project complexity factors evaluation in order to allow respondent answering naturally. Each project complexity factor has a weight varies from one (1) to Five (5) as following:

- Absolutely insignificant = 1 point
- Slightly insignificant = 2 points
- Neutral = 3 points
- Slightly significant = 4 points
- Absolutely significant = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between a set of project complexity factors from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test is tabulated in Table 16.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	16.9	11	1.53636364	1.40476759	0.16859421	1.81620939
Within Groups	380.6	348	1.09367816			
Total	397.5	359				

Table 16: Data Variance of Project Complexity Factors

Since P-value is greater than 0.05 and (F) is less than (F crit), then we do not reject the Null Hypothesis (H_0) which indicates that the means of the populations are equal. Answers were analyzed to provide the results as mean and standard deviation for each project complexity factor with respect to their effects on the project complexity level for industrial construction projects. Table 17 and Table 18 shows the responses mean, standard deviation and the ranking of each project complexity factor from the designer/consultant and constructor firms' perspectives respectively.

Project Complexity Factors	Mean	Standard Deviation	Rank
The degree of the project interferences with other ongoing projects	4.80	0.45	1
The degree of the project interferences with existing facilities and/or systems	4.40	0.55	2
Safety and/or security concerns	4.20	0.84	3
The project impact on the environment	4.20	0.84	
The project technology complexity and/or newness to project team	4.20	0.45	
Internal/External stakeholders' complexity	4.20	0.45	
The likelihood of major scope changes	4.00	0.71	4
Permitting and regulatory requirements	3.80	1.10	5
The construction site remoteness	3.60	0.55	6
The impact of the project delays	3.60	0.89	
Quality of suppliers, subcontractors, contractors	3.60	1.52	
The degree of the project sensitivity to the conditions of the markets	3.00	1.22	7

Table 17: Project Complexity Factors (Designers/Consultants perspective)

Project Complexity Factors	Mean	Standard Deviation	Rank
The degree of the project interferences with existing facilities and/or systems	4.22	1.09	1
The likelihood of major scope changes	4.09	1.12	2
Quality of suppliers, subcontractors, contractors	4.09	1.08	
Permitting and regulatory requirements	4.04	1.11	3
Safety and/or security concerns	4.00	1.17	4
The degree of the project interferences with other ongoing projects	4.00	1.04	
The impact of the project delays	4.00	1.04	
Internal/External stakeholders' complexity	3.91	0.95	5
The construction site remoteness	3.83	1.07	6
The project technology complexity and/or newness to project team	3.78	1.04	7
The degree of the project sensitivity to the conditions of the markets	3.57	1.04	8
The project impact on the environment	3.52	1.27	9

Table 18: Project Complexity Factors (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to rate the need of implementing constructability practices for industrial construction projects with respect to their complexity level. The questionnaire utilized five-points rate scale project complexity level evaluation in order to allow respondent answering naturally. Each project complexity level has a weight varies from one (1) to Five (5) as following:

- Not at all important = 1 point
- Slightly important = 2 points
- Moderately important = 3 points
- Very important = 4 points
- Extremely important = 5 points

One-Way ANOVA test has been utilized in this study to evaluate the variance between different project complexity levels from designer/consultant and constructor firms' perspectives. The output of the One-Way ANOVA test is tabulated in Table 19.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	35.2888889	2	17.6444444	24.5479744	3.5223E-09	3.10129576
Within Groups	62.5333333	87	0.71877395			
Total	97.8222222	89				

Table 19: Data Variance of Implementing Constructability for different Project Complexity levels

Since P-value is less than 0.05 and (F) is greater than (F crit), then we reject the Null Hypothesis (H_0) which indicates that the means of the two populations are not equal. Answers were analyzed to provide the results as mean and standard deviation for each project complexity level with respect to their needs of implementing constructability practices for industrial complex construction projects. Table 20 and Table 21 shows the responses mean and standard deviation of each project complexity level from the designer/consultant and constructor firms' perspectives respectively.

Project Complexity Level	Mean	Standard Deviation
Low complex construction projects	4.00	1.41
Medium complex construction projects	4.40	0.89
High complex construction projects	5.00	0.00

Table 20: The Need for Implementing Constructability (Designers/Consultants perspective)

Project Complexity Level	Mean	Standard Deviation
Low complex construction projects	3.04	0.88
Medium complex construction projects	3.78	0.80
High complex construction projects	4.65	0.71

Table 21: The Need for Implementing Constructability (Constructors perspective)

The participants from the owner, designer/consultant and constructor firms were asked to specify the required timing for implementing the constructability practices for industrial complex construction projects with respect to the project's complexity level. The participants were allowed to specify more than one phase of the project's life-cycle to conduct the constructability review. For industrial construction projects associated with High complexity level, the results indicate that the majority of the participants (93%) believes that the preliminary engineering phase is the required timing for conducting the constructability review, followed by (77%) and (67%) for detailed engineering phase and scoping phase respectively. Figure 55 and Figure 56 summarizes the results of the required timing for implementing the constructability practices for industrial construction projects with high complexity level.

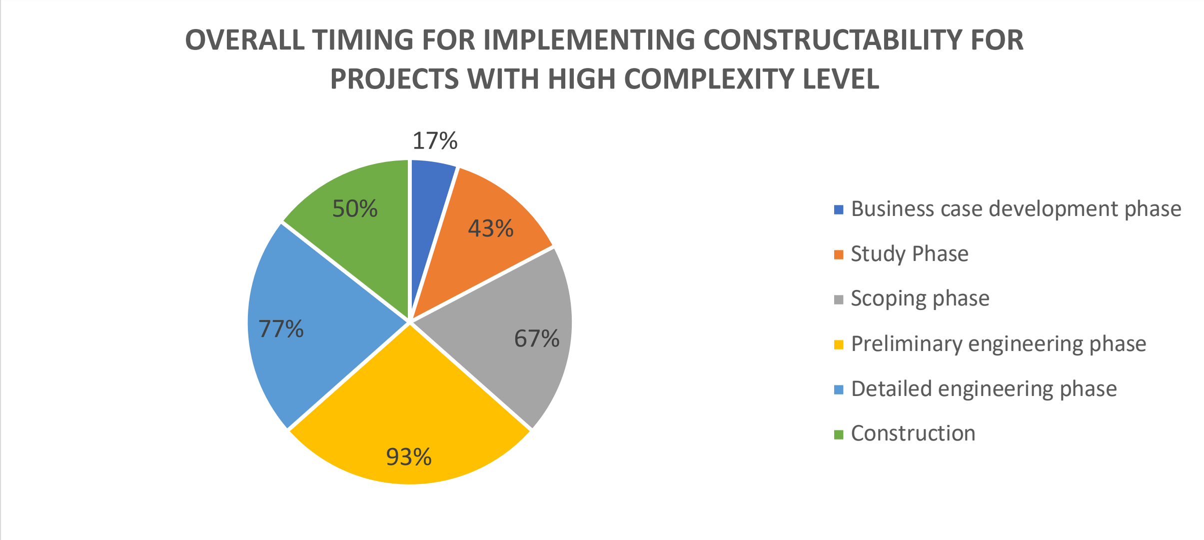

Figure 55:Overall Timing for implementing constructability for Projects with HIGH complexity Level

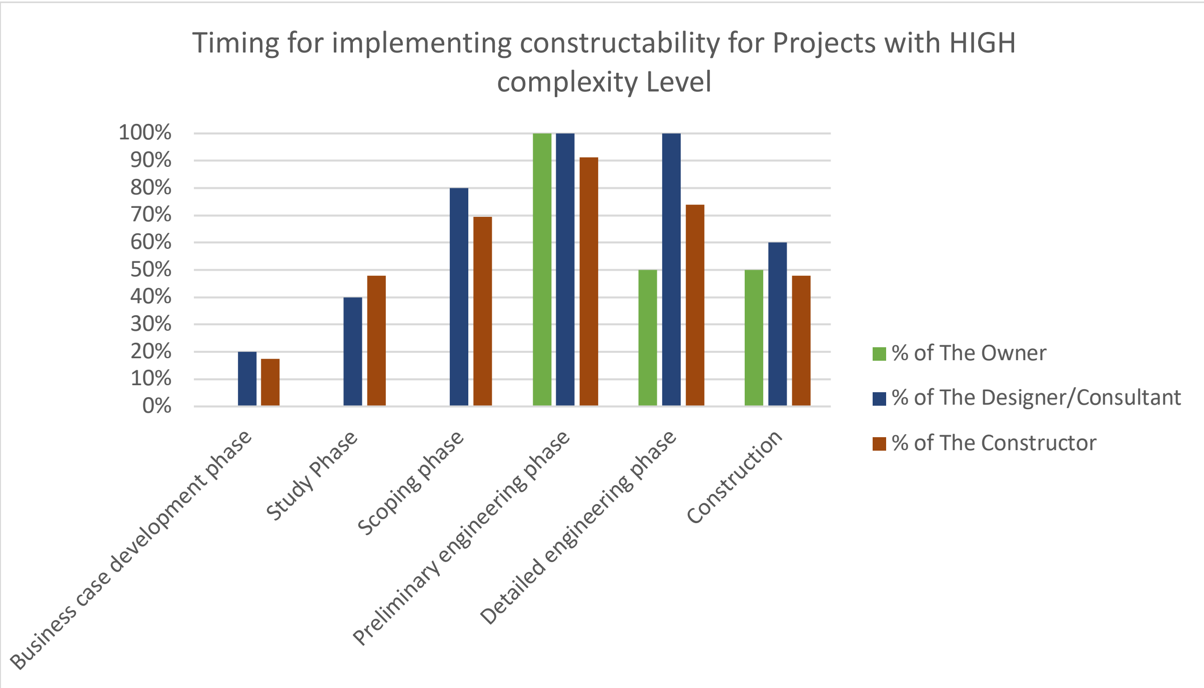

Figure 56: Timing for implementing constructability for Projects with HIGH complexity Level

For industrial construction projects associated with Medium complexity level, the results indicate that the majority of the participants (80%) believes that the preliminary engineering phase is the required timing for conducting the constructability review and (77%) of the them believes that it should be also conducted during the detailed engineering phase. Figure 57 and Figure 58 summarizes the results of the required timing for implementing the constructability practices for industrial construction projects with medium complexity level.

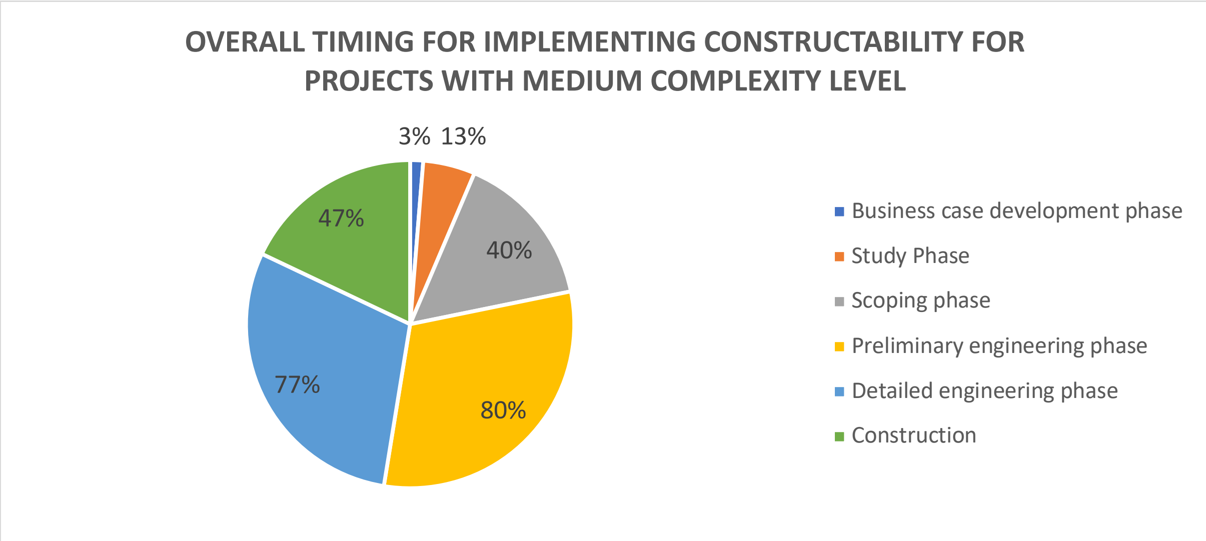

Figure 57: Overall Timing for implementing constructability for Projects with MEDIUM complexity Level

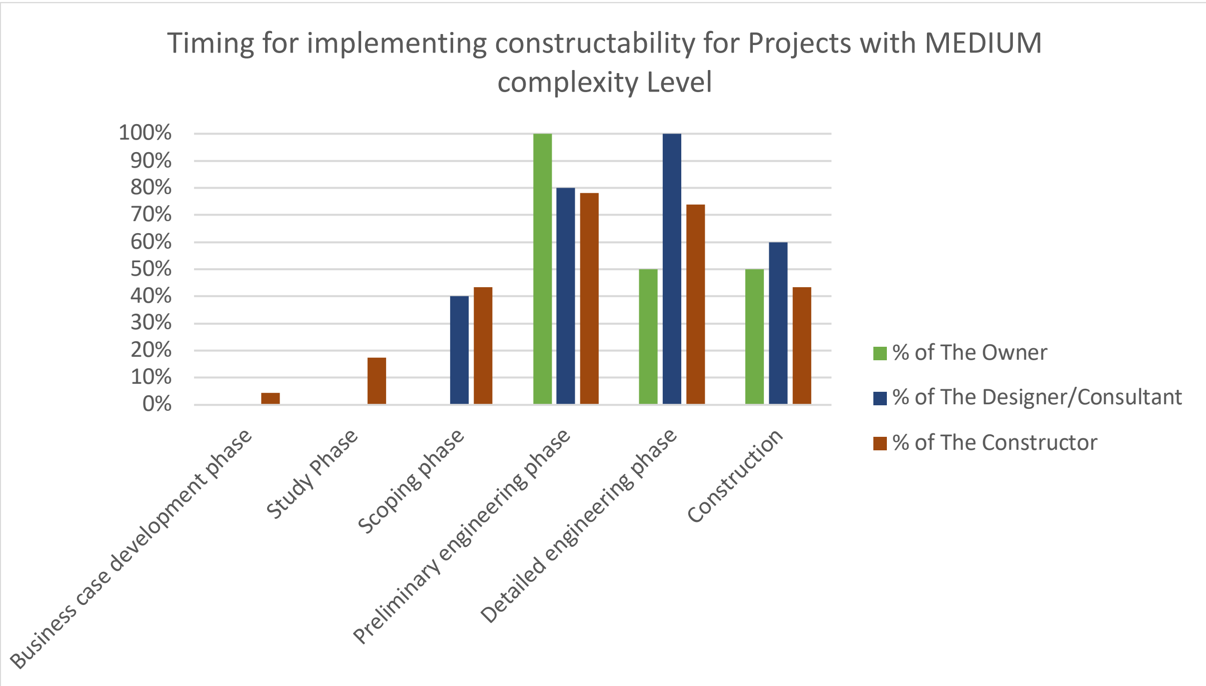

Figure 58: Timing for implementing constructability for Projects with MEDIUM complexity Level

For industrial construction projects associated with Low complexity level, the results indicate that the majority of the participants (70%) believes that the detailed engineering phase is the required timing for conducting the constructability review. Figure 59 and Figure 60 summarizes the results of the required timing for implementing the constructability practices for industrial construction projects with low complexity level.

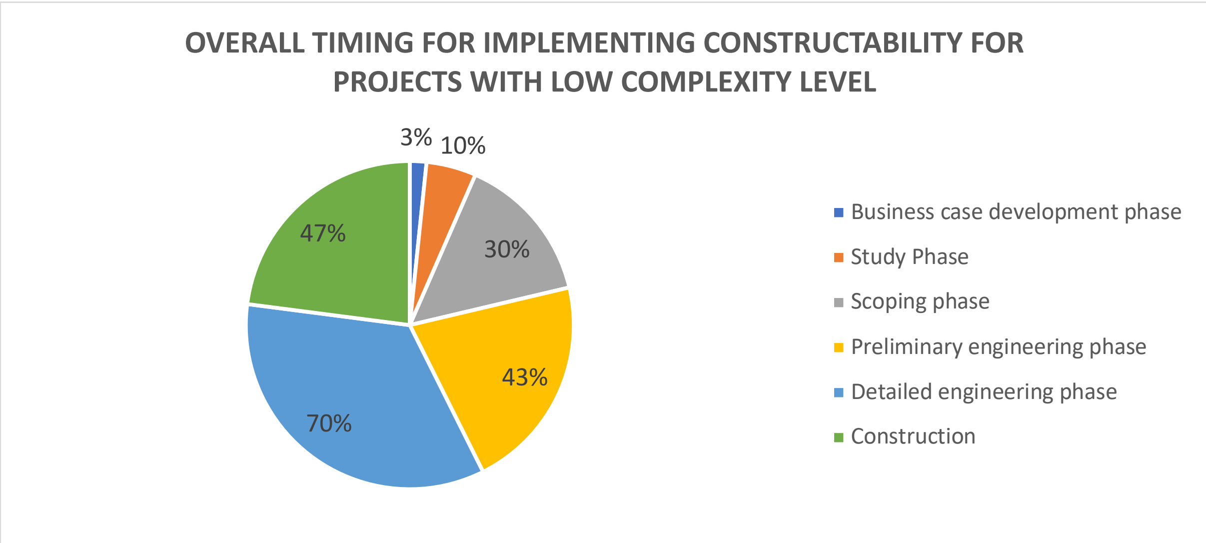

Figure 59: Overall Timing for implementing constructability for Projects with LOW complexity Level

Figure 60: Timing for implementing constructability for Projects with LOW complexity Level

It is worth mentioning that all participants from the designer/consultant and constructor firms agreed that the frequency of conducting constructability review is proportionally related to the project's complexity level.

4.3 The Case Study

4.3.1 Introduction

This part will discuss the selected case study of a construction industrial project, located in the Eastern Province of the Kingdom of Saudi Arabia, where constructability practices have been implemented throughout the project's life-cycle. This case study has been conducted by reviewing the project documents including reviewing the project categorization procedures, project requirements identification and constructability implementation practices at the corporate and project level for complex projects. In addition, conducting multible interviews with the project's key personnel including the Project Manager, Sr. Project Engineers, Project Engineers and Subject Matter Experts who have involved in categorizing the project, identifying the project requirements and/or involved in the constructability implementation.

4.3.2 Constructability at the corporate level

4.3.2.1 constructability implementation effort

The owner of the selected project is a semi-government company, based in Dhahran in the Eastern Province of the Kingdom of Saudi Arabia, works in the field of producing energy and chemicals. This company considered one of the first companies in the region that has implemented the Construction Industry Institute (CII) Best Practices. In fact, this semi-government company voluntary start uses of the CII Best Practices in 1993. Furthermore, in 2000, the company formally start implementing the CII Best Practices in all their industrial and non-industrial construction projects. The owner effort for ensuring the effectiveness of implementing constructability at the corporate level has been measured following the Construction Industry Institute (CII) Best Practices Guide (CII Implementation Resource 166-3) and can be demonstrated as following:

- The owner shows the obligation toward implementing constructability practices for each project at the early stage of the project development by developing an implementation procedure that determine the optimum timing for implementing the constructability practices based on the project's category;

- The owner shows the intent to eliminate all the barriers of implementing constructability practices by conducting internal and external assessments in order to identify and recognize the barriers and develop action plan toward continuous improvement of its constructability program. In addition, benefits of implementing constructability in terms of cost reduction and schedule optimization are measured against the targets adopted from Construction Industry Institute (CII) that has been further customized and extended to attain best-in-class status;

- The owner utilizes the Construction Industry Institute (CII) constructability roadmap and, as an active member of the CII research committee, the owner has also contributed toward continuous improvement of constructability implementation roadmap;

- At the earliest stage of the project, the owner ensure that the project's team has been identified along with their roles and responsibilities. In addition, all functional supporting organizations will be also identified to support the development of the project. As part of this integrated project team roles and responsibilities is to assure implementing constructability as per the company procedures. The owner assigns a subject matter expert to be the constructability sponsor who is supervise and facilitate the overall constructability program implementation where the integrated project team leader is assigned to be the constructability champion who is fully responsible for coordinating, tracking and documenting the constructability recommendations and aligning the integrated project team toward achieving common goals and objectives; and

- The owner fully understands the important of knowledge exchange and the lessons learned practices by developing lessons learned database where all employees can access this system easily for exploring other projects pitfalls, what are the suggested mitigation plan and their recommendations for other projects teams toward achieving more successful projects.

As mentioned above, the owner effort shows the intent to continuous improvement and boosting the performance level of its organization and projects at the corporate level.

4.3.2.2 constructability implementation roadmap

At the earliest stage, the company categorizes its projects into Four (4) main categories. This project categorization process is based on Two (2) main criteria. The first criterion is the Project Size which is mainly based on the estimated total capital value of the project. The second criterion is the Project Complexity factor associated with the project. The main objectives of categorizing the projects are as following:

- Define, within the company, the sponsorship level;
- Define the hierarchic of the project;
- Determine the required deliverables for each phase and stage of the project; and
- Determine the required resources to execute the project.

In addition of categorizing the project based on the project size and project complexity criteria, the company also classify the project based on Eighty (80) project subtypes in Nineteen (19) project types. This is to help the company to estimate the required services, manpower and materials.

Project size criterion:

The project size criterion is one of the two criteria that the company uses to determine the project category. The project size is defined by the estimated total capital value of the project. Total of Three (3) thresholds for the project size groups. The project size groups are; Large, Medium and Small Projects. Table 22 shows the project size groups along with its estimated total capital value range:

PROJECT SIZE GROUP	ESTIMATED TOTAL CAPITAL VALUE (Million)
Large projects	More than $500
Medium projects	$100 – $500
Small projects	$4 – $100

Table 22: Project Size Criterion

Project complexity criterion:

The project complexity criterion is one of the two criteria that the company utilizes to determine the project category. The complexity level of the project (High, Medium, Low complexity) is determined after identifying the complexity factor associated with the project. The complexity factor of a project is determined based on an evaluation of Eleven (11) complexity criteria in Three (3) major complexity groups. The project complexity criteria major groups are; Execution Complexity, Commercial Complexity and Stakeholders Complexity. Table 23 shows the project complexity criteria major groups along with its complexity criteria:

COMPLEXITY GROUP	COMPLEXITY CRITERION
Execution Complexity	The likelihood of major scope changes
	Safety and/or security concerns
	The project impact on the environment
	The construction site remoteness
	The degree of the project interferences with other ongoing projects
	The degree of the project interferences with existing facilities and/or systems
	The project technology complexity and/or newness to the company
Commercial Complexity	The degree of the project sensitivity to the conditions of eternal markets
	The impact of the project delays to the company
Stakeholders Complexity	Internal stakeholders' complexity
	External stakeholders' complexity

Table 23: Project Complexity Criterion

<u>Project categories:</u>

After defining the project size (Large, Medium or Small project size) based on the estimated total capital value and evaluating the project complexity level (High, Medium or Low complexity level), the company categorizes its projects into Four (4) main categories. Table 24 shows the Four main project categories:

PROJECT SIZE	PROJECT COMPLEXITY LEVEL	PROJECT CATEGORY			
		Category# 1	Category# 2	Category# 3	Category# 4
Large	High	X			
Large	Medium	X			
Large	Low		X		
Medium	High	X			
Medium	Medium		X		
Medium	Low			X	
Small	High		X		
Small	Medium			X	
Small	Low				X

Table 24: Project Categories

Project categorization process review:

Due to the dynamic nature of the construction industry, the company will validate and/or updates the project categorization process whenever needed. The validation includes reviewing the project size thresholds and reviewing the definition of each complexity criteria to determine whether it is still relevant to the company.

Project value improving practices:

At the earliest stage of the project, the integrated project team will determine the required value improving practices (biased on the project category and needs) to be carried out during the development of the project. The project value improving practices is a set of practices utilized by the integrated project team in order to improve and maximize the projects performance in terms of safety, quality, cost and schedule. These project value improving practices have been developed by the owner using the Construction Industry Institute (CII) practices, Society of American Value

Engineers (SAVE) standards, Value Engineering (VE) standards and the Project Management Institute (PMI) program on risk. These project value improving practices are as following:

- Best Practices: The owner utilizes a set of industrial best practices such as; Project Planning & Team Alignment (Project Execution Planning), Constructability, Planning for Startup, Project Definition Rating Index and Scope Control & Change Management. These best practices are conducted by the integrated project team thru multible workshops throughout the project life-cycle. The main aim and objective of the implementation of these industrial best practices is to support the integrated project team in delivering a complete project with a focus on the four key project objective areas of safety, quality, cost and schedule.

- Value Engineering: The owner has developed a Value Engineering Guide, by utilizing the Society of American Value Engineers (SAVE) and Value Engineering (VE) standards, which helps and supports the project integrated team to plan, organize and execute value engineering studies on the company's capital projects. The main aim and objective of the value engineering practices is to optimize the project execution and eliminating unnecessary costs without sacrificing total project quality, performance and reliability. As an outcome of these practices, the integrated project team will identify all the proposed/accepted ideas and recommendations that can be implemented to optimize the project execution.

- Project Knowledge Workshops: The owner has developed a group of programs that enhances the knowledge sharing culture within its organization. These knowledge sharing programs includes Lessons Learned Program Knowledge, Engineering Knowledge, Post Project Appraisal and Operations Knowledge. The main aim and objective of these knowledge sharing programs is to maximize knowledge exchange and prevent recurrence of issues encountered on previous and similar projects.

- Risk Management: The owner has developed a Risk Management Guide, by utilizing the Project Management Institute (PMI) program on risks, which helps and supports the integrated project team along with other stakeholders by providing a comprehensive detailed process to be followed in order to proactively minimize uncertainty in achieving the project objectives, maximizing project efficiency and facilitates the achievement of the organization objectives. In addition, the risk management practices will help the integrated project team to capture, assess all the project risks. Accordingly, the integrated project team will develop response plans and identify all activities required to monitor and manage these risks.

- Interface Management: The owner has developed the interface management practices that helps and supports the integrated project team to align all the project stakeholders toward common goals and objectives. The main aim and objective of the interface management practices is to identify interfaces among existing facilities and new projects and/or new project constructed by more than one construction contractor. The interface management practices will help and support the integrated project team to plan and manage the identified points of interfaces to maximize the project efficiency in terms of cost, schedule and quality.

According to the interviewed subject matter experts within the company, a recent assessment has been conducted by a consultant affiliated with the Construction Industry Institute (CII) to evaluate the maturity level of the above-mentioned project value improvement practices implementation. The assessment has been conducted by utilizing the Construction Industry Institute (CII) Self-Assessment Guide as an assessment tool. The assessment concludes that the company is well above others in the industry in terms of having a highly and comprehensive system for implementing the project value improvement practices. This shows how the owner is fully understands the importance and benefits of implementing the project value improvement practices which includes the constructability and lessons learned practices.

4.3.3 Constructability at the project level

4.3.3.1 project brief and scope

The selected case study is a construction industrial type of project located in the Eastern Province of the Kingdom of Saudi Arabia. The owner of this project is a semi-government company works in the field of producing energy and chemicals. The project major scope of work covers the demolition, removal and replacement of existing Twenty-nine (29) process equipment at Thirteen (13) different remote locations. The scope of work of this project covers also replacing all of these process equipment's associated piping, electrical and instrumentation. The purpose of this project is to meet the owner's crude program objective of maintaining crude oil production targets and improve plant safety.

4.3.3.2 constructability program implementation

Constructability program is part of the project value improving practices highlighted in Section 4.3.2.2. The main aim and objective of conducting constructability program is to improve and maximize the projects performance in terms of safety, quality, cost and schedule. The owner has determined the optimum implementation timing for constructability practices mainly based on the project category highlighted in Section 4.3.2.2. The integrated project team was not mandated to implement constructability during the business case stage, study and construction phases. However, it is only mandated to be conducted at the scoping, preliminary and detailed design phases.

- <u>Scoping phase:</u> During the scoping phase, the first implementation of the constructability was thru conducting constructability workshop at the 60% completion of this phase. This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). The participants are mainly stakeholders key personnel such as; project management, end user, inspection, designer and in some case construction personnel. The workshop facilitator was an approved 3rd party facilitator. However, the owner has developed subject matter experts to carry out such kind of workshops. During the workshop, the participants with the facilitator guidance went over and reviewed the Constructability Review Checklist which developed by the owner. The Constructability Review Checklist includes general constructability items covers all of the constructability concepts highlighted in Section 2.1.3. However, the participants have also added during the workshop other specific constructability related items for the project. Constructability report includes constructability review checklist (general/specific) items, its impact on cost and schedule, champion and due date of each item was issues and communicated to all members of the integrated project team and the designer.

- <u>Preliminary Engineering Stage:</u> During the preliminary engineering stage, the second implementation of the constructability was thru conducting constructability workshop at the 30% completion of this phase. This is applicable to all the projects categories (Category# 1,2,3 and 4). During the workshop, the participants with the facilitator guidance revisited the constructability review checklist (general/specific) items which reflects the status update of previous constructability items and action undertaken to ensure that all required actions have

- been reflected in the project design package and/or considered in the contract documents prior to the contract awarding to the construction contractor.

- Detailed Design Phase: During the detailed design phase, the third implementation of the constructability was thru conducting constructability workshop at the 20% completion of this phase. This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). Due to the selected project delivery system for this project (Traditional delivery system), this constructability workshop was the first time were the construction contractor's key personnel was involved in. During the workshop, the participants revisited the constructability review checklist (general/specific) items to ensure that all required actions have been reflected in the project design package prior to start of the construction activities.

Table 25 summarize the optimum implementation timing for constructability program for all the project categories:

Project phase/stage / ***Project category***	**Business Case**	**Study**	**Scoping**	**Preliminary Engineering**	**Detailed Design**	**Construction**
	Constructability	Constructability	Constructability @ 60%	Constructability @ 30%	Constructability @ 20%	Constructability
Category# 1	-	-	√	√	√	-
Category# 2	-	-	√	√	√	-
Category# 3	-	-	√	√	√	-
Category# 4	-	-	-	√	-	-

Table 25: Optimum Implementation Timing for Constructability Program

4.3.3.3 lessons learned program implementation

The lessons learned program is part of the project value improving practices highlighted in Section 4.3.2.2. This program can be divided into Two (2) main practices. First, Lessons Learned Implementation which is a structured and systematic approach to the application of lessons learned from previous projects. Second, Lessons Learned Collection which requires the integrated project team collectively documenting their unique experiences and insights from their involvement in the project. The owner has determined the optimum implementation timing for these Two (2) practices mainly based on the project category highlighted in Section 4.3.2.2.

- <u>Business Case Stage:</u> During the business case development stage, the integrated project team was not mandated to conduct the lessons learned program (implementation/collection). Due to the requirement of this stage which are mainly to validate the project business case feasibility and identify a comprehensive range of alternatives, the owner does not believe that this is the optimum implementation timing for the lessons learned program.

- <u>Study and Scoping Phases:</u> Likewise, the business case development stage, the integrated project team was not mandated to conduct the lessons learned program (implementation/collection) during the study phase. However, the integrated project team has started implementing this program in the scoping phase. The first implementation of the lessons learned program was thru conducting lessons learned implementation workshop at the beginning of the scoping phase (10% completion). This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). Prior conducting this workshop, the integrated project team's leader assigned a single point of contact to coordinate the workshop arrangements which mainly includes ensuring attendance of stakeholders key personnel (such as; project management, end user, inspection, technical services and designer), consolidate all pre-selected applicable lessons/pitfalls and share it to the workshop facilitator and along with all requited information about the project scope of work to successfully guide the workshop participants to areas of focus and critical lessons learned to be considered. The workshop facilitator was an approved 3rd party facilitator. However, the owner has developed subject matter experts to carry out such kind of workshops. During the workshop, the participants with the facilitator guidance agreed on the applicable lessons/pitfalls, how they might impact the project, level of criticality, plan of action and preliminary target completion dates. Lessons learned implementation plan report includes the required information to prevent and/or mitigate lessons/pitfalls from previous projects was issues and communicated to all members of the integrated project team and the designer.

The second implementation of the lessons learned program was thru conducting the first lessons learned collection workshop at the end of the scoping phase (100% completion). This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). During this workshop, the participants with the facilitator guidance have captured, analyses and documented the most significant lessons learned by the integrated project team. Lessons learned collection report was issued and communicated to all members of the integrated project team. This report was also shared and communicated to the subject matter experts for evaluation and updating the corporate lessons learned database.

- Preliminary Engineering Stage: During the preliminary engineering stage, the third implementation of the lessons learned program was thru conducting the second lessons learned implementation workshop at the beginning of the preliminary stage (10% completion). This is applicable to all the projects categories (Category# 1,2,3 and 4). During the workshop, the participants with the facilitator guidance revisited the plan of action that was generated during the first lessons learned implementation workshop to ensure that all required actions have been reflected in the project design package prior to the contract awarding to the construction contractor.

The forth implementation of the lessons learned program was thru conducting the second lessons learned collection workshop at the end of the preliminary stage (100% completion). This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). The second lessons learned collection report was issued and communicated to all members of the integrated project team and to the subject matter experts for evaluation and updating the corporate lessons learned database.

- <u>Detailed Design and Construction Phases:</u> During the detailed design phase, the fifth implementation of the lessons learned program was thru conducting the third lessons learned implementation workshop at the beginning of the detailed design phase (10% completion). This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). During the workshop, the participants with the facilitator guidance revisited the plan of action that was generated/updated during the second lessons learned implementation workshop to ensure that all required actions have been reflected in the project design package prior to the start of the construction activates.

  The sixth implementation of the lessons learned program was thru conducting the third lessons learned collection workshop at the end of the detailed design phase (100% completion). This is applicable to all the projects categories (Category# 1,2 and 3) except for projects that have low estimate total capital value and low level of complexity (Category# 4). The third lessons learned collection report was issued and communicated to all members of the integrated project team and to the subject matter experts for evaluation and updating the corporate lessons learned database.

  During the construction phase, the integrated project team was not mandated to conduct the lessons learned implementation workshop. However, it was mandated to conduct the fourth lessons learned collection workshop at the end of the construction phase (100% completion). In addition, the integrated project team was mandated to conduct separate lessons learned collection workshop with the end user six months after the project completion.

Table 26 summarize the optimum implementation timing for lessons learned program (implementation/ collection) for all the project categories:

Project phase/stage / ***Project category***	**Business Case**		**Study**		**Scoping**		**Preliminary Engineering**		**Detailed Design**		**Construction**	
	LLI @ 10%	LLC @ 100%	LLI @ 10%	LLC @ 100%	LLI @ 10%	LLC @ 100%	LLI @ 10%	LLC @ 100%	LLI @ 10%	LLC @ 100%	LLI @ 10%	LLC @ 100%
Category# 1	-	-	-	-	√	√	√	√	√	√	-	√
Category# 2	-	-	-	-	√	√	√	√	√	√	-	√
Category# 3	-	-	-	-	√	√	√	√	√	√	-	√
Category# 4	-	-	-	-	-	-	√	-	-	-	-	√

Table 26: Optimum Implementation Timing for Lessons Learned Program (Implementation/ Collection)

4.3.4 Constructability implementation benefits

Based on the conducted interview with the project key personnel from the integrated project team including the Project Manager, Sr. Project Engineers, Project Engineers and Subject Matter Experts who have involved in implementing the constructability program, the team believes that implementing the value improving practices have improved and maximized the project performance in terms of safety, quality, cost and schedule. In fact, the team believes that the implementation of constructability and lessons learned implementation practices have strongly contributed in achieving the project's targeted Key Performance Index (KPIs). Total of 45 constructability ideas/suggestions have been generated during the constructability workshops and the major benefits of implementing these constructability items highlighted by the integrated project team are as following:

- Constructability ideas/suggestions resulted in cost saving of 5-7% of the project allocated budget and 10-15% schedule optimization of the project completion schedule. Most of the cost saving and schedule optimization was contributed from the proper planning of procurement, logistics, cutover/shutdown and commissioning & start-up activities.

- Constructability ideas/suggestions resulted in meeting the corporate and the project targeted KPIs in terms of safety. Most of it was contributed from improving the site accessibility, ensuring the adequacy of the heavy lifting plan, adverse weather consideration and reducing the congestion of the construction area during peak load of project.

- Constructability ideas/suggestions resulted in meeting the corporate and the project targeted KPIs in terms of quality. Most of it was contributed from the developed QA/QC plan that was reviewed and approved by the owner prior of the construction activities.

Constructability ideas/suggestions resulted in increasing the integrated project team focus on common goal, increased commitment from the team members and smoothen the commissioning and start-up activities.

CHAPTER 5: SUMMARY OF THE STUDY, CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter will provide the readers with a summary of the study includes an overview of the main objective of the study along with an overview about the research methodology that has been followed to achieve the objective of the study. Furthermore, this chapter will present the major and minor findings, the study conclusion and its recommendation.

5.2 Summary of The Study

The constructability practices implementation become more important to prevent and/or mitigate any potential risks that may affect the project success due to the rapidly growth of the project complexity in the construction industry. The aim of this study is to investigate the impact of implementing constructability practices on the complex industrial construction projects in the Eastern Province of the Kingdom of Saudi Arabia. To achieve this objective, the level of practice of constructability, constructability implementation techniques, benefits, barriers and success factors along with the project complexity evaluation criteria was examined among the owners, designer/consultant and constructor firms which executes complex industrial construction projects in this part of the Kingdome. In this study, two data collection methods were implemented. The first method was developing and distributing a questionnaire containing close-ended questions with allowing the participants for more elaboration and/or specifying other answers. This questionnaire was distributed to all of the identified owner, designer/consultant and constructor firms who are executing complex industrial construction projects in this part of the Kingdome (Total of 47). Total of 30 responses were received and accepted (2 owners, 5 designer/consultant and 23 constructor firms). The second method was conducting a case study of a complex industrial construction project, located in the Eastern Province of the Kingdom of Saudi Arabia, where constructability practices were implemented throughout the project's life-cycle. The case study was conducted by reviewing the project documents including reviewing the project categorization procedures, project requirements identification and constructability implementation practices at the corporate and project level. In addition, conducting multible interviews with the project's key personnel including the Project Manager, Sr. Project Engineers, Project Engineers and Subject Matter Experts who have involved in categorizing the project, identifying the project requirements and/or involved in the constructability implementation.

5.3 Findings

This part of the paper summarizes the findings obtained from the distributed questionnaire among the owner, designer/consultant and constructor firms who are executing complex industrial construction projects in the Eastern Province of the Kingdom of Saudi Arabia. In addition, it will also summarize the findings obtained from the conducted case study of a complex industrial construction project, located in the Eastern Province of the Kingdom of Saudi Arabia, where constructability practices were implemented throughout the project's life-cycle.

5.3.1 Major findings

5.3.1.1 constructability implementation level in the Saudi Construction industry

The present study concluded that the owner, designer/consultant and constructor firms who are executing complex industrial construction projects in the Eastern Province of the Kingdom of Saudi Arabia are well-familiar and fully understand the importance of implementing the constructability concepts in their projects. in fact, all of the owner, majority of the designer/consultant and constructor firms do have a defined constructability program at the corporate level. However, both of the participated owner firms have agreed that the designer/consultant firms were/are lack of awareness/understanding of constructability concepts and they have not met their expectation for achieving the desired benefits. The present study concluded that, in general, most of the constructability concepts have been implemented by the participated owner, designer/consultant and constructor firms in their complex industrial construction projects.

Furthermore, it's been found that “Permanent and temporary site layouts promote efficient construction”, “Design elements are standardized” and “Designs facilitate construction and field productivity under adverse weather conditions” are the lest implemented constructability concepts among the participated owner firms.

Moreover, it's been found that “Development of the project contracting strategy involves construction knowledge and experience”, “Advanced information technologies are applied to facilitate efficient construction” and “Design elements are standardized” are the lest implemented constructability concepts among the participated designer/consultant firms.

Furthermore, it's been found that “Advanced information technologies are applied to facilitate efficient construction” and “Designs facilitate construction and field productivity under adverse weather conditions” are the lest implemented constructability concepts among the participated constructor firms.

5.3.1.2 constructability implementation techniques

The present study revealed that the “Corporate constructability log/file” technique was the most utilized technique among the owner firms, “Formal implementation process" was the most utilized technique among the designer/consultant firms and "Design review checklist was the most utilized techniques among the constructor firms for implementing constructability in their complex industrial construction projects.

5.3.1.3 constructability implementation benefits

The present study revealed that the "Reduce engineering and construction cost", "Reduce amount of rework" and "Improve site accessibility and project quality" benefits of constructability were the most significant benefits highlighted by the participated owner firms and the least significant benefits of constructability were "Increase problem avoidance", "Increase of understanding of purpose/ effective of individual's involvement" and "Increase commitment of the project team".

"Reduce amount of rework", "Improve the communication" and "Improve project quality" benefits of constructability were the most significant benefits highlighted by the participated designer/consultant firms and the least significant benefit was "Reduce engineering cost".

"Reduce amount of rework" benefit of constructability was the most significant benefit highlighted by the participated constructor firms and the least significant benefit was "Reduce engineering cost".

In addition, the present study revealed that the owner firms believes that implementing constructability in their complex industrial construction projects helped them to accomplished cost saving of more than 5% of the total project budget and schedule reduction of up to 7% of the total project duration while the majority of the designer/consultant and constructor firms believes that it helped them to accomplished cost saving of up to 3% of the total project budget and schedule reduction of more than 7% of the total project duration.

5.3.1.4 constructability implementation barriers

The present study concluded that, in general, the participated owns, designer/consultant and constructor firms in common were having the same opinion about the barriers to constructability, irrespective of the volume of work, type of work or type of contract.

The present study revealed that the “Lack of team-building or partnering (client - contractor relationship)”, “The designer were/are lack of awareness/understanding of constructability concepts”, “The designer were/are lack of construction experience/qualified personnel” and “The constructor had/ has poor communication skills” barriers to constructability were the most significant barriers highlighted by the participated owner firms and the least significant barrier to constructability was “The owner were/are lack of awareness/understanding of the concepts of constructability; no procedural (roadmap) is available”.

” Lack of team-building or partnering (client - contractor relationship)” was the most significant barrier highlighted by the participated designer/consultant firms and the least significant were “The constructor had/ has poor communication skills” and “Lack of mutual respect between designers and constructors”.

“The right people were/are not available” was the most significant barrier highlighted by the participated constructor firms and the least significant barrier were “Contractor or construction input is requested too late to be of value” and “Use of lump-sum competitive contracting”.

5.3.1.5 constructability implementation success factors

The present study concluded that, in general, the participated owns, designer/consultant and constructor firms in common were having the same opinion about the success factors for implementing constructability, irrespective of the volume of work, type of work or type of contract. The present study revealed that the “Developing competent constructability team”, “Understanding the project goals and objectives”, “Utilizing the lesson-learned database and best-practices for other projects”, “Early involvement of construction expertise at the project design phase”, “Early involvement of construction expertise in the development of the contracting strategy”, “Ensuring the implementation of the constructability recommendations” and “Ensuring the design simplicity for the construction personnel” success factors were the most significant success factors for implementing the constructability practices for complex industrial construction projects highlighted by the participated owner firms and the least significant success factors for implementing the constructability practices were “Ensuring the simplicity of the technical specifications for materials and equipment” and “Planning for preventive methods for unforeseen wither conditions”.

“Ensuring the implementation of the constructability recommendations” success factor was the most significant success factor highlighted by the participated designer/consultant firms and the least significant success factors were “Planning for preventive methods for unforeseen wither conditions”, “Ensuring the simplicity of the technical specifications for materials and equipment”, “Ensuring the standardization of the design elements”, “Ensuring the design simplicity for the construction personnel”, “Reviewing the applicability of the new developed construction technologies” and “Early determining the primary construction methods”.

“Utilizing the lesson-learned database and best-practices for other projects” and “Planning the sequence of the construction activities during the design phase” success factors were the most significant success factors highlighted by the participated constructor firms and the least significant success factor was “Planning for preventive methods for unforeseen wither conditions”.

Furthermore, the present study revealed that all of the participated owner and majority of the constructor firms agreed that the lessons learned practices are being affectively communicated across projects in their organizations. However, it’s been found that the participated designer/consultant firms believe that they need to put more effort for improving the communication of the lessons learned practices in their organizations.

Moreover, the present study concluded that the owner, designer/consultant and constructor firms are aware of the importance of communicating the constructability findings and/or recommendations by offering a specific section in their design bid documents for their complex construction projects addressing the constructability issues. The present study revealed that 64% of the participants are communicating the constructability findings and/or recommendations thru their design bid documents.

The present study revealed that the “Designer in-house constructability consultant” was the best choice for the participated owner firms for facilitating the constructability implementation in their complex industrial construction projects while the participated designer/consultant and constructer firms have selected “Third party constructability consultant”.

The present study revealed that the “Project manager, lead and project engineers (owner), ”End user representative”, “Lead project and discipline engineers (designer)”, “Construction manager and site project engineer (constructor)” and “Constructability consultant/ facilitator” key personnel were the most key personnel with respect to the importance of their involvement in conducting constructability review for complex industrial construction projects highlighted by the participated owner firms and the least importance key personnel involvement were “Site superintendent (constructor)” and “Discipline manager (designer)”.

“Lead project engineer (owner)”, “Construction manager (constructor)” and “Constructability consultant/ facilitator” were the most important key personnel highlighted by the participated designer/consultant firms and the least important was "Project manager (owner)".

"Construction manager (constructor)" was the most important key personnel highlighted by the participated constructor firms and the least important was "Discipline manager (designer)".

Furthermore, the present study revealed that all of the participated owner and majority of the designer/consultant and constructor firms are fully aware and understand the importance of the construction key personnel involvement during the early stages of the project design. According to the findings, 80% of the participated firms have agreed on the following statement "The involvement of construction key personnel during the early stages of the project design could enhance better constructible project".

5.3.1.6 project complexity factors

The present study revealed that the "The impact of the project delays" factor was the most significant factor with respect to their effect on the project complexity level for construction projects highlighted by the participated owner firms and the least significant complexity factor was "The project impact on the environment".

"The degree of the project interferences with other ongoing projects" factor was the most significant complexity factor highlighted by the participated designer/consultant firms and the least significant complexity factor was “The degree of the project sensitivity to the conditions of the markets”.

“The degree of the project interferences with existing facilities and/or systems” factor was the most significant complexity factor highlighted by the participated constructor firms and the least significant complexity factor was “The project impact on the environment”.

5.3.1.7 constructability implementation & project complexity level relationship

The present study revealed that, for industrial construction projects associated with High complexity level, the majority of the participants (93%) believes that the preliminary engineering phase is one of the required timing for conducting the constructability review, followed by (77%) and (67%) for detailed engineering phase and scoping phase respectively.

Furthermore, for industrial construction projects associated with Medium complexity level, the results indicate that the majority of the participants (80%) believes that the preliminary engineering phase is one of the required timing for conducting the constructability review and (77%) of the them believes that it should be also conducted during the detailed engineering phase.

Moreover, for industrial construction projects associated with Low complexity level, the results indicate that the majority of the participants (70%) believes that the detailed engineering phase is the best timing for conducting the constructability review.

In addition, the present study revealed that all participants from the designer/consultant and constructor firms have agreed that the frequency of conducting constructability review through the project life-cycle is proportionally related to the project's complexity level.

5.3.2 Minor findings

The present study revealed the following minor findings obtained from the distributed questionnaire among the owner, designer/consultant and constructor firms:

- All of the owner's and designer's/consultant's and majority of the constructor's complex construction projects are executed with only Two (2) contract types (fixed price and unite rate).

- All of the owner's and majority of the designer's/consultant's and the constructor's complex construction projects are executed with Two (2) project delivery systems (Traditional "Design-Bid-Build" and Turnkey). The results also indicated that the Design-Build project delivery system has not been utilized enough among the owner and constructor firms in their complex construction projects.

- 67% of the participants are very familiar with the constructability concepts and practices.

- 86% of the participants have the opportunity to have on the job training and/or was enrolled in training courses conducted by their organizations for better implementation of the constructability concepts.

- 26% of the constructor's participants do not know if their organization does have a constructability program at the corporate level or not. Hence, the present study concluded that there is a lack among the constructor firms for not communicating their corporate constructability program across their organization.

- The majority of the participated owner, designer/consultant and constructor firms indicated that the fee for conducting the constructability review is ranging from $15,000 to less than $20,000 for each complex industrial construction project.

- It has been found that complexity, in concept, can be understood in various ways in different fields and sometimes even within the same field. Moreover, there is a lack of accepted conceptual definition for complexity among researchers. In fact, there is no standard definition for the project complexity that is applicable to all the construction project cases. Hence, there is a need to define the project complexity and study it's attributes and what can influence the complexity of any project.

5.4 Conclusion

The Saudi construction industry considered one of the largest construction industries in the region. Currently, most of the projects in the Saudi construction industry are for re-building the Kingdome infrastructure which considered as complex projects due to many factors. Due to the complexity nature of re-building the Kingdome infrastructure, the constructability practices implementation become more important to prevent and/or mitigate the project risks that may affect the project success. Constructability can be one of the construction management tools that can be utilized to resolve and minimize the construction project complexity. A construction project can be considered as a complex system due to several factors that are difficult to be controlled by the project management. Managing projects to achieve its fundamental goals requires to identify certain critical characteristics and some researches in the construction industry pointed out that the project complexity is one of those critical characteristics. Even if the project team have all the needed information about the project, project complexity will still exist which make it difficult to keep every part of the project under control.

Many studies and research have been done in the constructability field, yet still there is lack of researches and studies that links the project complexity level with the constructability practices. The main aim and objective of this study is to investigate the impact of implementing constructability practices among the owner, designer/consultant and constructor firms who are executing complex industrial construction projects in the Eastern Province of the Kingdom of Saudi Arabia. To achieve the main aim of this study, a questionnaire containing close-ended questions with allowing the participants for more elaboration and/or specifying other answers was developed and distributed among the owner, designer/consultant and constructor firms. In addition, a complex industrial project among the Saudi construction industry that has implanted constructability concept was selected and analyzed as a case study. The level of constructability implementation, constructability implementation techniques, benefits, barriers & success factors and project complexity factors were covered to achieve the main aim and objective of the study. Moreover, major and minor findings obtained from the conducted case study and/ or the distributed questionnaire were presented and discussed along with the study recommendations.

5.5 Recommendation

Depending on the findings of this study, the study recommends the following course of action toward promoting the complex industrial projects in the Saudi construction industry

- The owner, designer/consultant and constructor firms are encouraged to ensure implementing the constructability practices irrespective of the volume, type of work, type of contract, project delivery system of their complex industrial construction projects.

- The owner, designer/consultant and constructor firms are encouraged to frequently assist their constructability program at the corporate level to identify opportunities for improvement.

- The owner, designer/consultant and constructor firms are encouraged to ensure to evaluate the applicability of each constructability concept during the constructability review and address them accordingly.

- The owner firms are encouraged to ensure considering the permanent and temporary site layouts, standardize the design elements and adverse weather conditions during their constructability review.

- The designer/consultant firms are encouraged to ensure considering the construction personnel qualifications as part of the contract framework, evaluate the utilization of the current developed construction technologies and standardize the design elements during their constructability review.

- The constructor firms are encouraged to ensure considering the adverse weather condition and evaluate the utilization of the current developed construction technologies during their constructability review.

- The owner, designer/consultant and constructor firms are encouraged to continually document all benefits obtained from implementing any idea generated during their constructability review.

- The design/consultant firms are encouraged to put more effort toward improving and boosting their employee’s awareness/understanding of constructability concepts.

- The owner, designer/consultant and constructor firms are encouraged to ensure that the right individuals are part of the constructability implementation team.

- The owner, designer/consultant and constructor firms are encouraged to ensure promoting effective team-building among project personnel and keeping them focused on common objectives.

- The designer/consultant firms are encouraged to establish a program and/or agreement with their clients (owner and/or constructor firms) allowing them to obtain their client's lessons learned from each design package they have developed after being implemented or during the construction phase.

- The owner, designer/consultant and constructor firms are encouraged to ensure utilizing their lesson-learned database and/or best-practices during their constructability review and should ensure the implementation of the constructability recommendations.

- The owner, designer/consultant and constructor firms are encouraged to communicate the constructability findings and/or recommendations by offering a specific section in their design bid documents addressing the identified constructability issues.

- The owner, designer/consultant and constructor firms are encouraged to establish their own criteria and methodology for measuring the project complexity level.

5.6 Areas for Further Studies

This study came out with a few recommendations for future studies. Further study should be carried out, such as investigate the impact of implementing constructability practices among the owner, designer/consultant and constructor firms who are executing non-industrial complex projects in the Saudi construction industry. Another suggested study is to define the project complexity and study it's attributes and what can influence the complexity level of any project.

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VITAE

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APPENDIX

Appendix- A: The Questionnaire

CONSTRUCTABILITY QUESTIONNAIRE

Dear participant:

I would like to solicit your support by answering this questionnaire. I am a graduate student in Construction Engineering and Management at King Fahd University of Petroleum and Minerals (KFUPM). I am conducting a study on the Constructability implementation for complex industrial projects in the Saudi construction industry for my master's Thesis. The main aim and objective of this study is to investigate the impact of implementing constructability practices on the private and semi-government complex industrial projects in the Saudi construction industry.

The questionnaire should not take more than 15 minutes. Your responses will be kept anonymous and confidential. Only aggregate results will be presented or documented. Your contribution in the study is strictly voluntary. If you are interested in the results of this study and/or you need any further information, please contact me at *0542992244* or via email *ALMUFADHI@GMAIL.COM*

Best Regards,

CONSTRUCTABILITY QUESTIONNAIRE

Section_1: Respondent

This section contains questions seeking information on the characteristics of the participant.

1. **What is your current job title?**

   Mark only one oval.

   - Project Manager
   - Sr. Project Engineer
   - Project Engineer
   - Constructability specialist/ facilitator
   - Other: ____________________

2. **How many years of experience you have in the business of construction projects?**

   Mark only one oval.

   - Less than 5 years
   - 5 to less than 10 years
   - 10 years to less than 15 years
   - more than 15 years

3. **What is your level of education?**

   Mark only one oval.

   - Diploma
   - BSc
   - MSc
   - PhD
   - Other: ____________________

4. **What is your degree discipline?**

   Mark only one oval.

   - Civil Engineering
   - Mechanical Engineering
   - Chemical Engineering
   - Electrical Engineering
   - Industrial Engineering
   - Management
   - Other: ____________________

5. **What professional certificate you have?**
Check all that apply.

- [ ] Project Management Professional (PMP)
- [ ] Fundamentals of Engineering (FE)
- [ ] Professional Engineer (PE)
- [ ] PMI Risk Management Professional (PMI-RMP)
- [ ] Program management Professional (PgMP)
- [ ] Other: ____________________

6. **What professional association you are member in?**
Check all that apply.

- [ ] American Society of Civil Engineers (ASCE)
- [ ] American Society of Mechanical Engineers (ASME)
- [ ] Project Management Institute (PMI)
- [ ] Society of Petroleum Engineers (SPE)
- [ ] Other: ____________________

7. **How many construction projects you have been involved in?**
Mark only one oval.

- ◯ Less than 2 projects
- ◯ 2 to less than 4 projects
- ◯ 4 to less than 6 projects
- ◯ more than 6 projects

8. **How many constructability reviews for construction projects you have participated?**
Mark only one oval.

- ◯ Less than 2 constructability reviews
- ◯ 2 to less than 4 constructability reviews
- ◯ 4 to less than 6 constructability reviews
- ◯ More than 6 constructability reviews

9. **Have you received any kind of training to enhance your knowledge about constructability before conducting the constructability review?**
Check all that apply.

- [ ] In-house training course
- [ ] Self training
- [ ] On the job training
- [ ] I had no training
- [ ] Other

10. **How do you rate your level of familiarity with the constructability concept and practices?**
Mark only one oval.

- ◯ Very well-known
- ◯ Well-known
- ◯ Average familiarity
- ◯ Slight familiarity
- ◯ Unkown

Section_2: Organization

This section contains questions seeking information on the characteristics of the participant's organization

11. **How many years has your organization been in the business of construction projects?**
Mark only one oval.

- ◯ Less than 10 years
- ◯ 10 to less than 15 years
- ◯ 15 to less than 20 years
- ◯ 20 to less than 25 years
- ◯ More than 25 years

12. **How many complex construction projects does your organization execute annually?**
Mark only one oval.

- ◯ Less than 2 projects
- ◯ 2 to less than 10 projects
- ◯ 10 to less than 20 projects
- ◯ 20 to less than 40 projects
- ◯ More than 40 projects

13. **What is the average percentage of complex construction projects types does your organization execute?**
Check all that apply.

	Approximate Percentage (%)
General Buildings (commercial, housing, etc.)	☐
Heavy civil work (infrastructure)	☐
Industrial (process oriented)	☐
Others	☐

14. **What is the average percentage of complex construction project size your organization executed? (MM= Million)**
Check all that apply.

	Approximate Percentage (%)
Less than $50MM	☐
50 to less than $100MM	☐
100 to less than $200MM	☐
200 to less than $500MM	☐
More than $500MM	☐

15. **What is the average percentage of contract type your organization used for complex construction projects?**
Check all that apply.

	Approximate Percentage (%)
Fixed price	☐
Unit rate	☐
Cost plus	☐
Other	☐

16. **What is the average percentage of project delivery system your organization used for complex construction projects?**
Check all that apply.

	Approximate Percentage (%)
Traditional (Design-Bid-Build)	☐
Turnkey	☐
Design-Build	☐
Other	☐

17. **How often do you offer a specific section in the design bid documents for complex construction projects addressing the constructability issues?**
Mark only one oval.

- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ Often
- ◯ Always

18. **What best describes your organization?**
Mark only one oval.

- ◯ End user (owner)
- ◯ Construction agency (project management)
- ◯ Contractor (construction contractor)
- ◯ Designer
- ◯ Consultant
- ◯ Other: ____________________

Section_3: Constructability Implementation

This section, which is considered the main section of the questionnaire, contains questions seeking information related to the constructability implementation among the complex industrial projects in the Saudi construction industry.

19. **Does your organization have a corporate constructability program?**
Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ I don't know

20. **What are the techniques used in your organization for the constructability review for complex construction projects?**

Check all that apply.

- [ ] Formal implementation process
- [ ] Corporate constructability log/file
- [ ] Design review checklist
- [ ] Peer review
- [ ] Brainstorming
- [ ] Other: ______________________________

21. **Based on your experience, rate all the following barriers with respect to their effect on the implementation of constructability practices in complex construction projects?**
Mark only one oval per row.

	Absolutely insignificant	Slightly insignificant	Neutral	Slightly significant	Absolutely significant
Complacency with the status quo	◯	◯	◯	◯	◯
The "right people" were/are not available	◯	◯	◯	◯	◯
the owner were/are lack of awareness/understanding of the concepts of constructability; no procedural "roadmap" is available	◯	◯	◯	◯	◯
Owner perception that "we do it"	◯	◯	◯	◯	◯
Lack of team-building or partnering (client - contractor relationship)	◯	◯	◯	◯	◯
the owner misdirected the design objectives and designer performance measures	◯	◯	◯	◯	◯
Use of lump-sum competitive contracting	◯	◯	◯	◯	◯
The owner's reluctance to invest additional money, effort, and time in early	◯	◯	◯	◯	◯
Designer perception that "we do it";	◯	◯	◯	◯	◯
The designer were/are lack of awareness/understanding of constructability concepts and/or	◯	◯	◯	◯	◯
The designer were/are lack of construction experience/qualified personnel	◯	◯	◯	◯	◯
Lack of mutual respect between designers and constructors	◯	◯	◯	◯	◯
Contractor or construction input is requested too late to be of value	◯	◯	◯	◯	◯
Poor timeliness of input for the constructor	◯	◯	◯	◯	◯
The constructor had/ has poor communication skills; design criticism is often non-constructive or communicated in a offensive, tactless manner	◯	◯	◯	◯	◯

22. **Based on your experience, rate all the following benefits as a result of implementing the constructability practices in complex construction projects?**
Mark only one oval per row.

	Completely disagree	Disagree	Neutral	Agree	Completely agree
Reduce engineering cost					
Reduce construction cost (labor, material and equipment)					
Reduce schedule duration					
Reduce amount of rework					
Reduce disruption to current production					
Reduce maintenance cost					
smoothen the start-up					
Increase problem avoidance					
Increase of understanding of purpose/ effective of individual's involvement					
Increase commitment of the project team					
Increase construction flexibility					
Improve the communication					
Improve project quality					
Improve project safety					
Improve site accessibility					
Enhance team building and cooperation					

23. **Based on your experience, rate all the following key personnel with respect to the importance of their involvement in conducting constructability review for complex construction projects?**
Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Project manger (owner)					
Lead project engineer (owner)					
Project engineer (owner)					
End user representative					
Discipline manager (designer)					
Lead project engineer (designer)					
Discipline engineer (designer)					
Construction manger (constructor)					
Site superintendent (constructor)					
Site project engineer (constructor)					
Constructability consultant/ facilitator					

24. **Who do you think is the best for facilitating the constructability review for complex construction project?**

Check all that apply.

- [ ] Owner in-house constructability consultant
- [ ] Desiger in-house constructability consultant
- [ ] Constructor in-house constructability consultant
- [ ] Third party constructability consultant
- [ ] Other: ______________________________

25. **Based on your experience, rate the following success factors for implementing the constructability practices for complex construction projects?**
Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Developing competent constructability team	⬭	⬭	⬭	⬭	⬭
Understanding the project goals and objectives	⬭	⬭	⬭	⬭	⬭
Utilizing the lesson-learned database and best-practices for other projects	⬭	⬭	⬭	⬭	⬭
Integrating the constructability as part of the project execution plan	⬭	⬭	⬭	⬭	⬭
Early involvement of construction expertise at the project design phase	⬭	⬭	⬭	⬭	⬭
Early involvement of construction expertise in the development of the contracting strategy	⬭	⬭	⬭	⬭	⬭
Early development of the project schedule goals as construction driven	⬭	⬭	⬭	⬭	⬭
Early determining the primary construction methods	⬭	⬭	⬭	⬭	⬭
Studying the site layout (site access, fabrication yard, storage area and truck roads ... etc.)	⬭	⬭	⬭	⬭	⬭
Ensuring the implementation of the constructability recommendations	⬭	⬭	⬭	⬭	⬭
Reviewing the applicability of the new developed construction technologies	⬭	⬭	⬭	⬭	⬭
Planning the sequence of the construction activities during the design phase	⬭	⬭	⬭	⬭	⬭
Ensuring the design simplicity for the construction personnel	⬭	⬭	⬭	⬭	⬭
Ensuring the standardization of the design elements	⬭	⬭	⬭	⬭	⬭
Ensuring the simplicity of the technical specifications for materials and equipment	⬭	⬭	⬭	⬭	⬭

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Reviewing the applicability of the modularization and preassemble concepts during the design phase	⬭	⬭	⬭	⬭	⬭
Reviewing the resources allocation and its accessibility to the project's site at the design phase	⬭	⬭	⬭	⬭	⬭
Planning for preventive methods for unforeseen wither conditions	⬭	⬭	⬭	⬭	⬭
Developing the plan for start-up during the design phase	⬭	⬭	⬭	⬭	⬭
Utilizing the construction innovation during the construction phase	⬭	⬭	⬭	⬭	⬭

26. **Based on your experience, what is the average percentage fee for conducting the constructability review with respect to the project allocated budget for complex construction projects?**

Mark only one oval.

- ⬭ Less than $5,000
- ⬭ $5,000 to less than $10,000
- ⬭ $10,000 to less than $15,000
- ⬭ $15,000 to less than $20,000
- ⬭ More than $20,000

27. **Based on your experience, what is the average percentage schedule reduction that you can anticipate by implementing the constructability practices for complex construction project?**

Mark only one oval.

- ⬭ Less than 1% of the total project duration
- ⬭ 1% to less than 3% of the total project duration
- ⬭ 3% to less than 5% of the total project duration
- ⬭ 5% to less than 7% of the total project duration
- ⬭ More than 7% of the total project duration

28. **Based on your experience, what is the average percentage cost saving that you can anticipate by implementing the constructability practices for complex construction project?**

Mark only one oval.

- ◯ Less than 0.05% of the total project duration
- ◯ 0.05% to less than 1% of the total project budget
- ◯ 1% to less than 3% of the total project budget
- ◯ 3% to less than 5% of the total project budget
- ◯ More than 5% of the total project budget

29. **If you did participate in one of the constructability reviews for complex construction projects, select all the constructability concept covered during the review**

Check all that apply.

- ☐ Constructability implementation plans are an integral part of the Project Execution Plan
- ☐ Early project feasibility planning takes advantage of construction knowledge and experience
- ☐ Development of the project contracting strategy involves construction knowledge and experience
- ☐ Project schedules are construction - and startup-sensitive
- ☐ Important, early design decisions consider modularization/preassembly, construction automation, and other major construction method options
- ☐ Permanent and temporary site layouts promote efficient construction
- ☐ Advanced information technologies are applied to facilitate efficient construction
- ☐ Design and procurement schedules are construction-sensitive
- ☐ Designs are configured to enable efficient construction and use of efficient technologies
- ☐ Design elements are standardized
- ☐ Procurement, construction and startup efficiency are considered in the development of contract documents
- ☐ Module/preassembly designs facilitate fabrication, transport, and field installation
- ☐ Designs promote construction accessibility of personnel, material, and equipment
- ☐ Designs facilitate construction and field productivity under adverse weather conditions
- ☐ Project plans enhance security during construction
- ☐ Innovative construction management and field methods are applied to increase construction efficiency

30. **If you did participate in one of the constructability reviews for complex construction projects, select all the constructability principles covered during the review:**
Check all that apply.

- [ ] Project Integration: The constructability must be part of the developed project plan
- [ ] Construction knowledge: The construction expertise must be involved in the project planning phase
- [ ] Team skills: The project team must be selected based on their experience, knowledge and skills requirement for the project
- [ ] Corporate objectives: The project team need to understand the project objectives as well as the client's objectives so that the constructability can be enhanced
- [ ] Available resources: In the project's design phase, the available resources (manpower skills, equipment and technologies) must be considered
- [ ] External factors: External factors such as; unforeseen bad weather, political issues ...etc. could affect the project cost and/or schedule
- [ ] Program: The project program must be construction-sensitive, realistic and have the commitment of the project team
- [ ] Construction methodology: In the project's design phase, the construction methodology must be considered
- [ ] Accessibility: In the project's design and construction phase, the construction accessibility need to be considered to enhance the project's constructability
- [ ] Specifications: The projects constructability can be enhanced by developing transparent specifications
- [ ] Construction innovation: The projects constructability can be enhanced using innovation ideas during the construction stage
- [ ] Feedback: The projects constructability can be enhanced by utilizing the lesson-learned databases and best-practices for other projects

31. **Based on your experience, rate the following statement " The involvement of construction key personnel during the early stages of the project design could enhance better constructible project "**
Mark only one oval.

- ◯ Completely disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Completely agree

32. **Based on your experience, rate how effectively the lessons learned being communicated across projects in your organization?**
Mark only one oval.

- ◯ Very poor
- ◯ Poor
- ◯ Fair
- ◯ Good
- ◯ Excellent

33. **Based on your experience, rate the following factors with respect to their effect on the project complexity level for construction projects?**
Mark only one oval per row.

	Absolutely insignificant	Slightly insignificant	Nutral	Slightly significant	Absolutely significant
The likelihood of major scope changes	⬭	⬭	⬭	⬭	⬭
Safety and/or security concerns	⬭	⬭	⬭	⬭	⬭
The project impact on the environment	⬭	⬭	⬭	⬭	⬭
The construction site remoteness	⬭	⬭	⬭	⬭	⬭
The degree of the project interferences with other ongoing projects	⬭	⬭	⬭	⬭	⬭
The degree of the project interferences with existing facilities and/or systems	⬭	⬭	⬭	⬭	⬭
The project technology complexity and/or newness to project team	⬭	⬭	⬭	⬭	⬭
The degree of the project sensitivity to the conditions of the markets	⬭	⬭	⬭	⬭	⬭
The impact of the project delays	⬭	⬭	⬭	⬭	⬭
Internal/External stakeholders complexity	⬭	⬭	⬭	⬭	⬭
Quality of suppliers, subcontractors, contractors	⬭	⬭	⬭	⬭	⬭
Permitting and regulatory requirements	⬭	⬭	⬭	⬭	⬭

34. **Based on your experience, rate the need of implementing constructability practices for construction projects with respect to their complexity level?**
Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Low complex construction projects	⬭	⬭	⬭	⬭	⬭
Medium complex construction projects	⬭	⬭	⬭	⬭	⬭
High complex construction projects	⬭	⬭	⬭	⬭	⬭

35. **Based on your experience, specify the required timing for implementing constructability practices for construction projects with HIGH complexity level?**
Check all that apply.

- [ ] Business case development phase
- [ ] Study Phase
- [ ] Scoping phase
- [ ] Preliminary engineering phase
- [ ] Detailed engineering phase
- [ ] construction

36. **Based on your experience, specify the required timing for implementing constructability practices for construction projects with MEDIUM complexity level?**
Check all that apply.

- [ ] Business case development phase
- [ ] Study Phase
- [ ] Scoping phase
- [ ] Preliminary engineering phase
- [ ] Detailed engineering phase
- [ ] construction

37. **Based on your experience, specify the required timing for implementing constructability practices for construction projects with LOW complexity level?**
Check all that apply.

- [ ] Business case development phase
- [ ] Study Phase
- [ ] Scoping phase
- [ ] Preliminary engineering phase
- [ ] Detailed engineering phase
- [ ] construction

End of the questionnaire